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THE

EDINBURGH ENCYCLOPÆDIA,

CONDUCTED BY

DAVID BREWSTER, L.L.D. F.R.S.

With the assistance of

GENTLEMEN EMINENT IN SCIENCE AND LITERATURE.

THE

FIRST AMERICAN EDITION,

Corrected and improved by the addition of numerous articles relative to

THE INSTITUTIONS OF THE AMERICAN CONTINENT,

ITS GEOGRAPHY, BIOGRAPHY, CIVIL AND NATIONAL HISTORY, AND TO VARIOUS DISCOVERIES IN

SCIENCE AND THE ARTS.

IN EIGHTEEN VOLUMES.

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THE AMERICAN EDITION

OF THE NEW

EDINBURGH ENCYCLOPÆDIA.

MUSCI,

AN extensive, natural, and well-defined family of plants, belonging to the class Cryptogamia of Linnæus's artificial system, and to the division Acotyledones of Jussieu's method.

The essential character of this family, as we choose to term it provisionally, though there can be little doubt, that in the final arrangement of the Acotyledones, it will form a distinct class,—is derived from the fruit; which is a capsule of one cell, covered with a free membrane, termed Calyptra, which, when the plant is in flower, invests the style, and forms a great part of the stigma.

The natural character of this family is, to have the flowers monoecious or dioecious, rarely polygamous or united; in some species they are unknown.

Calyx monophyllous, tetraphyllous, or polyphyllous, sometimes absent.

Corolla, none; but the Calyptra, which is properly an exterior covering of the Pistil, is usually so termed by authors.

Stamina, generally numerous in the same flower, sometimes solitary. Anther, on a filament, sessile, or embedded; spherical, ovate, or cylindrical; opening elastically by the separation of a lid, or by an irregular aperture. Pollen, either a viscid fluid, clear, or milky;—or farinaceous, very abundant, forming a dense cloud when it escapes; varying in colour in different species.

Pistilla, generally numerous. Ovarium sessile. Style cylindrical or flattened; stigma rounded at first, afterwards flat, or cup-shaped.

Pericarp, a capsule, generally raised on a fruitstalk, produced after the flower; sometimes sessile.

Seeds, in general numerous, more or less spherical or oval; surface smooth, rough, or echinated; substance peculiar; after the evolution of the plumula and radicle, jointed, branched, conferva-like shoots, arise from different parts of the seed.

Receptacle, generally proper. When the male flowers form powdery heads, it seems to be common. In the female flowers, no instance of a common receptacle is known, except in the genus Marchantia.

In the plants of this family, the structure is cellulose; the stem leafy or frondose; rarely leafless; leaves simple and quite entire, or serrated, or ciliated; in other instances laciniate, more or less deeply; in several instances two-lobed; the lobes in general unequal in size; sometimes furnished with stipules. Minute plants; never shrubby; of annual, biennial, or perennial duration; varying in size from a line or little more, to three or four feet, growing on trees, rocks, dry or moist earth, in bogs, in running or in stagnant water.

Affinity in the flowers and fruit.—With the dicotyledoneous genus Calyptranthes, on account of its calyptraeform corolla—With Ferns, on account of the peculiar structure of the seed—*In the vegetation*, on account of resemblance in general aspect, with various cotyledoneous plants, some of which have the resemblance noted in their specific name. Such are, Saxifraga muscoides, hypnoides, bryoides; Tillaea muscosa; Moehringia muscosa; Forstera muscifolia; Lithophila muscoides; Andromeda hypnoides.

With Lycopodineae, the affinity is so considerable, that the whole of this tribe was placed by Linnæus in his order Musci, notwithstanding the very great discrepancy in the fruit, and in the internal structure of the stem. A recently discovered member of this family, Lycopodium hypnoides, has the exact aspect of Hypnum aduncum; another, Lycopodium scorpioides, no less exactly, that of Hypnum scorpioides. In Dufourea trifaria of Bory St. Vincent and Willdenow, there is the fructification of a Lycopodinea, with the habit of Fontinalis squamosa.

Of Filices, a considerable number come in minuteness and delicacy of aspect, pretty near to the Mosses; such as Acrostichum muscosum, Polypodium musco-

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sum, Trichomanes muscoides, and various other species;—indeed, a considerable proportion of the minute Ferns in general.

With the Foliaceous Lichens, the Musci of the genera Targionia Riccia, Marchantia, Anthoceros, and the frondose species of Jungermanniae, have considerable affinity.

Among the aquatic Algæ, we find a considerable number of species, which, by their tenuity and feathered appearance, have a considerable resemblance in aspect to the Mosses; and some species and varieties have at different times received names expressive of this resemblance. One widely diffused species of Fucus, figured by Mr. Turner in Hist. Fucor. t. 127, retains the name of F. musciformis. A variety of F. aculeatus, (Turn. t. 187.) was described by Linnæus under the name of F. muscoides. To F. tenuissimus, (Turn. t. 80.) the name of muscoides has been given by Wulfen; and to two different varieties of F. corneus, (Turn. t. 157.) the name of F. hypnoides has been given by two different celebrated writers. And we possess some specimens of species of Conferva, from good Herbaria, which had received, many years ago, the names of leskcoides, bryoides, muscoides, obviously on account of their resemblance to this species of family.

Uses of Mosses.

Though this title may at first extort a sarcastic smile from those who are more conversant with the writings of Pope and Akenside, than with the pursuits of natural history; and though they may be disposed to ask, whether the discussion under it should not be as short and conclusive as that in the chapter of Horrebow's History of Iceland, entitled, "Concerning serpents," which states only, that no serpents are to be found in any part of the island;—yet surely a moment's reflection should be sufficient to furnish even those readers with an answer to their own sarcasm. We are informed, by the Inspired Historian of the Creation, that *God pronounced good every thing which he had made;* and surely nothing that the Deity has pronounced good, can be unworthy of the contemplation of man. Every physical research, when properly conducted, must be, like Galen's treatise of anatomy, a Hymn to that Great Being by whom all things were at first formed, and are still upheld.

Perhaps, from the very minuteness, and apparent insignificance, on a superficial glance, of the plants to be treated under this article, an argument may be found in favour of the study of them. It has been observed by a writer, equally eloquent and profound, that *Man is placed in the middle between the two infinities—the infinitely great, and the infinitely little, both of which are equally incomprehensible to him.*[*] Of these two extremes, it is perhaps the most useful to recall the attention frequently to the latter. The infinitely great forces itself upon our attention. The changes that occur in the universe, on the great scale, can scarcely fail to occupy occasionally the thoughts of even the busiest, and the least reflecting; while they will be a favourite theme with those who have more leisure, and are blessed with a contemplative turn of mind. But the infinitely little, and whatever approaches to it, is less obtrusive. It does not at first affect the mind with a feeling of sublimity almost overpowering, like the former. On the contrary, we are apt to pass it without attending to it at all; or to slight it as insignificant, if it chance to catch our attention. Yet, not less than the great orbs revolving in the immensity of space, do objects, almost mocking human sense by their minuteness, furnish a field inexhaustible for scientific investigation; and to the student of Final Causes, the minutest object furnishes a proof of design as convincing as the largest. In order to demonstrate those truths which form the basis of natural religion, Paley preferred an examination of the structure of the human body, to a survey of the universe; and Boyle considered the eye of a fly as being to man a better proof of design than the sun himself, though the life and soul of our planet; because we have better means of becoming acquainted with the minuter objects compared, than with the greater. Wherever the adaptation of parts to the attainment of an end can be traced, the proof of design is complete; and he who could examine the nutrition, the growth, the regular conformation; the provision made for the continuation of the species, while all the individuals successively disappear, of even the minutest Phascum, without perceiving in them proofs of intelligence, power, and goodness, would probably receive no more conviction from the sublimest truths that astronomy can unfold.

This noblest use of scientific inquiry in general might be attained then, in the study of mosses, from the consideration of their structure alone; even although we were unable to assign any purposes which they serve in the economy of nature, or any advantage derived by man or by the lower animals, from mosses in general, or from any particular member of the family. But purposes of utility subserved by mosses in every one of these points of view, have not escaped observation; and it is our purpose now to mention some of them, as a not unsuitable introduction to the details which are afterwards to be given, in regard to structure and arrangement.

Scarce any considerable portion of dry land, which is not incapable of supporting vegetation of any sort, is totally destitute of mosses. Even in very productive pasture fields, we shall find some Gymnostoma, various Phasca, some Tortulæ, perhaps some Didymodontes and Brya; and Hypna also are seldom wanting, though in fine fields recently *laid down*, the Hypna will probably be the most sparing. These, like most other mosses, flourish chiefly in the humid wintry half of the year, when other plants are in their worst plight. They tend to preserve the green covering of the earth, and thus to increase its beauty; and they foster the roots of other plants with a genial warmth and moisture, thus rendering them less easily destroyed than they might otherwise be, by intense frosts, and sudden vicissitudes of temperature in winter, and by periods of long drought or sultry heat in summer. In densely shaded woods, where few cotyledoneous plants will vegetate, the ground is frequently clothed chiefly with the long, slender, elegantly recumbent, and tufted stems of the silvan Hypna; among which H. prælongum, proliferum, splendens, striatum, loreum, triquetrum, squarrosum, purum, trichomanoides, denticulatum, complanatum, and undulatum, may be noted as among the most conspicuous in Britain. The Orthotricha, some Hypna, the rare Zygodon, one Gymnostomum, and some other mosses, contribute to diversify the scene still more, by growing elegantly attached, in little tufts, to the living trunks and branches of the trees themselves; and various mosses hasten to cover them as soon as their living principle is extinguished, and decomposition begins to take place. The aquatic mosses quickly vegetate in marshes, ditches, and stagnant waters. They are supposed to have an unceasing tendency to the purification of those waters; and there can be no doubt that they contribute not a little to the formation of a *humus*, or vegetable mould, which insensibly rises above the water; thus converting a quagmire into a fertile field, and rendering that which was unprofitable and hurtful to the country in which it occurred, a new source of wealth and of strength to it. Among the mosses useful in this respect, may be mentioned the four Sphagna, various Brya, as palustre, dealbatum, hornum, punctatum, &c.; various Hypna, as aduncum, cordifolium, cuspidatum, scorpioides, &c.; various Dicrana, as glaucum, pellucidum, squarrosum, adiantoides, &c.

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[*] Pascal, Pensées, Edit. Renouard, vol. i. p. 182—186.

From this unquestionable tendency of aquatic mosses, a very imposing use of them has been imagined as probable, at that early period in the history of the globe, when the primeval waters first retired or subsided, and left exposed the projecting portions of the solid nucleus of the earth. The surface of the land would then be covered with mud, equally unfit for the growth of the larger terrestrial plants and of land animals. But it was then in a very favourable state for the support of a large proportion of the family of Mosses; and with the exception of projecting rocks, all the parts of the earth which had completely emerged were covered with a velvet-like carpet of verdant moss. Equiseta, Carices, various marsh Gramineæ, aquatic and marsh dicotyledons, may be supposed to have come successively to their aid; and thus, in a series of ages, the vegetable humus on the surface of the earth to have been formed.

Nor, if it be allowable at all to speculate about the formation of the crust of the earth, ought this supposition to be at once thrown aside as quite extravagant. That peat-moss consists of the remains of vegetables, preserved in astringent water, is no longer a matter of doubt. In numerous instances, the very species of plants, of which the peat-moss, or a great part of it, is composed, may be ascertained even at the depth of many feet below the surface. Peat-moss is usually stratified, and in many instances a stratum consists almost exclusively of one species of plant. The sorts of plants which have been found to go most frequently, each by itself, to the constitution of a single stratum, are mosses, Cyperaceæ, and coarse grasses. Layers of several feet in thickness, consisting almost entirely of Sphagna, are not unknown. Nay, in moorlands, and other situations, where extensive tracts are frequently covered with any one of the four species of Sphagnum, or with two or more of them, the process of nature in transforming the moss into peat, may be distinctly traced. For a certain depth from the surface, say a foot, the plants are living and vigorous; throughout the second foot, the plants are more or less decomposed; throughout the third foot, sometimes the stems of the identical plants that are growing luxuriantly on the surface, can be distinctly traced, but their vitality is gone; a large proportion of the leaves are disorganized; and the stems and branches are consolidated into the state of a soft, spongy, highly inflammable, light brown peat. Nor are the Sphagna the only mosses, of which alone or chiefly a layer of peat-moss has been found to consist. The late Professor Walker of Edinburgh had seen, in Annandale, a thin layer of peat-moss, which had been formed of the remains of Hypnum fluitans. And in the vale of Sanchy, M. Faujas St. Fond discovered, at the depth of *eight feet* below the surface, a stratum of peat-moss *eleven feet thick*, which seemed to consist entirely of Hypnum aduncum. And not merely mosses of such a firm consistency as Sphagna, Hypna, Dicrana, Brya, Trichostoma, and so on, but, what would scarcely be anticipated, some, even of the delicate Jungermanniæ, have been found many feet below the surface, in such a state that the specimens could be referred, with perfect accuracy, to existing species. And it is established, by a profusion of evidence, that, in favourable circumstances, peat-moss will grow to several feet in thickness, in less than the average period of a human life. See PEAT-MOSS.

Even projecting masses of rock may in time acquire a covering of humus by means of mosses and other minute plants. Such bare surfaces afford attachment in the first instance to Lepraria, Lecideæ, crustaceous Endocarpa, Isidia, or other minute lichens. The foliaceous lichens and mosses next attack these, and in turn give way to grasses, and others of the larger plants. In such situations, and on walls, not turf-capt, patches of earth, an inch or more in depth, may frequently be found to be collected by little tufts of Tortula muralis, Didymodon purpureum, Grimmia pulvinata, Bryum cæspititium, B. capillare, or various other mosses, in ten or twelve years, or even in a shorter time. In a word, neither marshes nor rocks, nor, it may be added, a soil consisting of mere sand, or the most steril clay, provided moisture be present, is destitute of mosses; and in all these situations they prepare the way for plants more obviously useful.

The uses of mosses hitherto mentioned, relate rather to the economy of the globe in general, than to man, or to any of his " fellow wanderers of the earth" in particular. Some instances of their utility in this more humble, but not less interesting relation, may next be stated.

It has already been mentioned, that mosses protect the roots of plants against the too intense rays of the scorching summer sun. This general use is imitated in the garden on a smaller scale, by covering with moss the flower-pots containing tender plants, during an intense heat. In like manner, in winter, delicate plants are frequently protected from frost by means of mosses.

It is a not unfrequent subject of complaint with the practical agriculturist, that in process of time his pasture grounds are rendered unproductive by means of mosses, and that, in order to free himself from their intrusion, he must submit to the trouble of irrigating, manuring, or tilling his pasture grounds, when perhaps it may be very inconvenient to perform any of these operations upon them. But do we, on inquiry, find sufficient ground for this complaint? If we examine the roots of mosses, we find that, with the exception of the Polytricha, the tree-like species, Hypnum dendroides, H. alopecurum, and Bryum ligulatum, and a few others, none of which occur plentifully in pasture grounds, scarce any of them penetrate an inch below the surface. Frequently the fibrillæ which constitute their secondary roots,—those roots by which most mosses are nourished throughout the greater part of their existence,—are not more than a line or two, and in very few instances half an inch in length; and when any part of the moss occurs deeper, it will be found that, with few exceptions, a part of them has been covered with the soil, either accidentally, or in consequence of a humus forming around it. It appears, then, very improbable, that mosses should be hurtful by impoverishing the soil, as they can affect only its very superficies; and the only impoverishing influence which can be urged against them, with any show of reason, is of a negative nature, and arises from the densely tufted mode of growth, so common in the family, by which the fertilizing influence of the air must be to a certain extent excluded. But this inconvenience is surely more than counterbalanced by the advantages derived from the decomposition of the lower part of the stems, and the lower leaves of the mosses themselves. There appears, then, no reason to suppose, that mosses can be hurtful by impoverishing the soil; and indeed, when we consider the shortness of the roots of most of them, the places where, and the times when they vegetate, it seems in the highest degree probable that they derive most of their nutriment from water, or from humid air. But instead of limiting ourselves to the negative argument, that mosses are not hurtful, there appears to be good reason for taking up the positive one, that, in the circumstances of the case, mosses are truly beneficial to those pastures in which they occur, even in the greatest abundance. Let us, for instance, suppose the mosses to disappear from a field, at the time when the agriculturist is making his bitterest complaints of them, every thing else remaining as it was. We should then find the roots of the sickly scattered plants to which the agriculturist confines his care, very much exposed. A part of them would most likely be burnt up, even by the average heat of a British summer; another part of them destroyed by the intense colds of *black frosts* during winter; and a proportion, perhaps greater than that destroyed by either, or even both of the former means, be thrown out of the soil altogether to perish, by the alternate frosts and rains of spring.

It has not yet been established that mosses, in any instance, usurp the place of the higher tribes of plants. They frequently prey upon Lichens, sometimes upon Fungi, Confervæ, and other actyledoneous plants; but to the cotyledoneous they appear always to give place; and it is only when the grasses of agriculturists are disappearing from the pasture grounds, that mosses arise; and they come as friends to the surviving plants, to fill up the vacant space, and protect them equally against extremes of heat and cold. Various circumstances are always co-operating to lessen the number of grasses in our fields. The scythe passes over them, before their seeds are matured and shed, that they may afford an agreeable and nutritious food for cattle; in spring, the cattle gnaw away the tender creeping shoots; in autumn, domesticated herbivorous animals in general, but more particularly horses, frequently bite so close as to injure the central part of the root. The pastured animals are continually trampling upon, and crushing those roots with their feet; and the injury done by this means during wet weather, particularly in low pasture grounds, is often very great. Besides, the surface soil is exhausted annually by the growth of those plants, without being remunerated by their decaying leaves and stems, or in any other adequate manner. Hence it happens, that pasture fields, if neither irrigated nor manured, become, after a greater or less number of seasons, incapable of yielding their accustomed produce, or perhaps any thing but mosses. In such circumstances, if you take away the mosses, the number of other plants will not be increased; they will only be exposed to the more speedy destruction. Is any additional illustration wanted of the position, that mosses do not supplant the grasses and other cotyledoneous plants, but only come to supply their vacant place, till they shall be in a condition again to resume it? Let a piece of ground, completely mossed over, be enclosed and left at rest—be converted to a plantation, for example—and in two seasons it will, in general, be covered with luxuriant herbage, the term luxuriant being understood relatively to the degree of richness of the soil, as evinced by its former average produce. If the ground cannot be left at rest, then increase the pabulum for other plants, and the mosses will disappear. Should the deficiency of grasses arise from their having been eradicated or destroyed, in whatever manner, then sow again their seeds, and the mosses will remain no longer than is necessary to foster them by their shelter, and a suitable degree of moisture, while they are germinating and fixing their tender roots.

It is not yet quite certain what influence mosses, parasitical upon trees, exert towards their supporters. That they cannot be hurtful by abstracting the juices of the trees, is certain; because in no instance do they penetrate through the epidermis. The only conceivable mode then in which they could do harm, would be by obstructing perspiration, preventing the access of fresh air, or as a harbour for insects. But unless in the last of these modes, it is not in the least probable that mosses, properly so called, are injurious; as of the British species, which occur either constantly or pretty generally upon trees, scarce any that spread extensively, forming a dense mat, take possession of a trunk, till it has been already completely covered with Lichens—plants that are perfectly air-tight, and that often adhere like a plaster to a great part, or even the whole of a trunk, and almost the whole of the branches too. It is these plants chiefly, not musci, which have incurred the malediction of the gardener, under the name of *the moss*. The numerous species which occur densely matted around the roots of forest-trees seem to be beneficial, by protecting them from radiant heat, and from *black or dry frost*, (frost without snow.) At all events, the fact is certain, that in forests the largest trees, while perfectly healthy and vigorous, often support the greatest quantity of moss; and on the most exposed side of the tree; or, if all sides be equally exposed, on that against which the severest and most frequent storms beat, the greatest quantity of moss, and of Lichen too, occur. In such instances it is not improbable that the moss may be advantageous to the tree, as a protection against the storm. And when you find a tree completely mossed over, in a languishing condition, a little examination will invariably, or at least almost invariably, show sufficient cause for the sickliness, independent of the *mossing*. The central part of the trunk is either converted to touchwood, or altogether gone, showing the tree to be dying of old age, or some disease sufficient to explain its appearance, or it is in a soil, situation, exposure, or climate, unfavourable to it; whence the malady,—and not from the moss.

Several species of animals find a considerable resource in mosses, on interesting occasions. It has been observed, that against the approaches of winter, the Arctic bear lines his cave well with Polytrichum commune. According to Linnæus, the rein-deer are wont to brouse in winter on the Sphagna, as well as on Cetraria rangiferina. The squirrel's round and elegant pendulous nest, which serves not less as a comfortable retreat from the wintry blast, than as a warm and safe habitation for the young, is chiefly formed of mosses. With these plants, too, some species of the vulture and hawk tribe, line the rugged fabric of their twig-built nests; and a considerable proportion of the passerine tribes construct their elegant temporary domiciles nearly of mosses alone. No inconsiderable number of the Insecta and Vermes of

Linnæus, find in mosses a shelter much to their liking; and some of them make of these plants a staple article of food. The fruit seems to be the part of the plant which they relish most; and that of Buxbaumia aphylla, to be with some *slugs* a peculiar dainty; as was experienced lately in a manner not at all to his satisfaction, by a Scottish collector of mosses of our acquaintance. Delighted with the discovery of a new and pretty abundant habitat of that rare moss, he sent off a live sample, carefully packed in a box with other live mosses, to a friend in the south, as a proof of his good fortune. But the precious moss suffered sadly on the way, from a little slug that had found means to insinuate itself into the package. It had made free also with some of the leaves of Hookeria lucens.

Nor are mosses altogether destitute of utility in domestic economy, and in the arts. In Lapland, during summer, a bed of Polytrichum commune is as much prized as a bed of heath in the Highlands of Scotland; and for this Lappish luxury, those speculators who are fond of referring every human custom to an imitation of some instinct of the inferior animals, may find a precedent in the anecdote of the white bear, already related. In the same country, are also pillows and chair-bottoms stuffed with moss; and cottagers collect considerable quantities of it against winter, in their humble dwellings. Of Polytrichum commune, mattresses are made, superior to those of straw. By the Laplanders, also, the Sphagna are used as cradle clothes; and Linnæus views this substitution for linens or flannel with much complacency. "Quippe muscus ille urinam absorbet, quod alia non efficiunt vestimenta." In Sweden and other northern countries, Polytrichum commune and various Hypna, are used as filtres for milk. In Britain, Polytrichum commune, gathered from a moist peat-moss, where it grows luxuriantly, reaching a foot or 18 inches in height, makes an excellent besom. Some Hypna, for instance H. purum and H. schreberi, are occasionally used by fishermen for scouring their bait. Some of the larger species of the same genus, particularly H. triquetrum, form, on account of the length and elasticity of their stems, an excellent packing for glass, porcelain, stoneware, and other brittle substances. In Sweden and Russia, where many houses are fabricated of wood, the chinks are often stopped with Hypnum splendens (hence often called H. parietinum) H. proliferum, H. prælongum, and others. With Hypnum fluitans, according to Loesel, houses are sometimes thatched in Prussia. In Sweden, Fontinalis antipyretica, densely stuffed behind the chimney, is used to protect the walls of cottages against the action of the fire. Of mosses have been constructed icehouses, not inferior to those formed of any other material. In mosses may bulbous and other roots be conveyed in safety from the greatest distance. By having their trunks and branches wrapped up in moss, delicate exotic trees are often recovered by gardeners from a languid state. In mosses, as was discovered by Apuleius Geoponus, in the 14th century, apples may be preserved with great success. And as mosses contribute very materially to the formation of peat-moss, it is evident that they enter in a staple article of fuel in the north of Europe—though, according to Abilgaard, the peat which had been formed from moss alone, is inferior as fuel to that which contains a portion of other materials. (Abilg. vom Torfe. Hafniæ 1765.)

On the tinctorial properties of mosses, few experiments have been made; but Damburney states, that from a decoction in water of mosses which he gathered from the trunk of a beach, he obtained elegant *couleur de vigogne.* (Recueil d'Observ. &c. p. 253.)

In medicine, formerly, several mosses were considered as of great efficacy; but now, the whole family may be considered as abandoned by the physician. A species of Marchantia—M. conica, from a rude analogy, which may be traced between the appearance of its surface and that of the liver, was once in use as a potent remedy against all hepatic disorders. The *λειχην* of Dioscorides is generally supposed to be either Marchantia conica, or Peltidea canina; and it derives its name from its supposed efficacy against a cutaneous disease so termed. Polytrichum commune and Funaria hygrometrica, the Adiantum aureum majus and minus of old pharmaceutical writers, were both celebrated and used as of wonderful virtue against very many diseases. So late as the 16th century, Fuchsius stated, that a decoction of these mosses in water, applied externally, strengthens the roots of the hair, and even renews the hair after it has fallen off; taken internally, it is a good expectorant, diuretic, lithontriptic, and that it cures the king's evil besides. Bauhin, in the 17th century, states, that in his days pedlars were wont to hawk about long stalks of Polytrichum commune, variously twisted, which were purchased with avidity by the ignorant, as remedies of universal efficacy. That moss was considered as possessed of great magical virtue; and a relict of the superstitious regard in which it was formerly held, may be traced in a use to which, according to Bridel, it is still put in some parts of Germany—that of protecting the cradles of infants from the effects of witchcraft. By Linnæus, all the high-sounding virtues formerly attributed to it, were pronounced to be apochryphal; yet Dillenius asserts, on his own authority, that it is good against pulmonary affections. Tournefort celebrates its sudorific properties; and Bucholz has ascertained that these properties are much concentrated in a distilled water obtained from it. In Lapland, according to Linnæus, the Sphagna, moist, and without being heated, are applied to œdematous feet; and in Dalia, a decoction of Fontinalis antipyretica has been used as a pediluvium in fever. A sudorific property has been attributed to the Hypna, perhaps on no better account than the literal signification of the name, although that name had been arbitrarily transferred by Dillenius and Linnæus to certain mosses, from some lichen which Dioscorides vaguely designated by it.—But it is unnecessary to say more of the medicinal uses of mosses, since the whole family is disregarded in modern practice; and, for aught that is known to the contrary, with reason. The whole family seems to possess a slight degree of astringency. Polytrichum commune, which has been used as an emetic, may owe the activity of its properties, superior to that of the properties of most other mosses, to the gallic acid which has been found in its constitution. The chemical constitution of mosses is scarcely at all known; and the gum, extractive and calcareous earth which have been found in some members of the family, are too trifling in amount to admit of any practical conclusion being drawn from their presence.

The further investigation of the uses of mosses, we recommend to the lovers of this elegant tribe of plants, as a field for the exercise of their ingenuity scarcely less promising than the description and arrangement of species.

Geographic Distribution of Mosses.

As the distribution of plants over the globe depends chiefly on the distribution of heat, the tropical, the temperate, and the polar regions, have each a distinct character in their vegetable productions. In the tropical region, plants of the most majestic appearance, palms, arborescent ferns, and trees with splendid blossoms, adorn the woods; the lawns are oft covered with gigantic grasses of two. three, or even four yards in height; and Liliaceæ, Scitamineæ, and other herbs with the largest and most beautiful blossoms, stud the fields. In this region, mosses, though they occur wherever there is moisture and shade, are in a general view rare, except at a considerable elevation on the mountains.

In the temperate region, palms and arborescent ferns are wanting; the flowers of the forest trees are so small and so destitute of show, as to be, in common language, denied the name; the grasses are in general small plants, their shoots and foliage forming a dense entangled turf; and the daisy, crowfoot, and bugloss, take the place of the Liliaceæ and other splendid plants of the tropics. Mosses and lichens are plentiful, and acotyledoneous plants in general form from a third to a half of the species of vegetables. Within the polar region, trees are, in a general view, scarce. Some pines, and the white birch, which advance farthest, at last disappear, and the dwarf-birch, some dwarf salices, as S. glauca, reticulata, and herbacea, for a time supply their place, in a herbage of coarse grasses and cyperaceæ, with mosses and lichens intermingled. Still farther within the region, mosses and lichens, and some minute fungi, are left sole occupants of the land; the mosses next cease to grow; and Uredo nivalis, which inhabits the surface of the snow itself, forms the northern limit of the vegetable tribes. The different floræ, however, though in a general view sufficiently well characterized in each region, pass, by imperceptible gradations, into each other; and, in the tropical region, on ascending mountains, as the heat decreases, we fall in successively with a flora analogous to that of the temperate and polar regions; in like manner, on ascending a mountain in the temperate region, we find, at a certain distance below the snow line, the commencement of a polar flora.

Most families of plants are limited to a certain range of climate; but mosses are dispersed nearly over the whole surface of the globe. If they are peculiarly luxuriant and plentiful on the inner side of the polar circle, and towards the snow line in the tropical and temperate regions, it is on account of the humidity of the soil and climate, which is peculiarly favourable to their vegetation; and the absence, or small proportion of cotyledoneous plants, which leaves them full scope for growth. The extent of ground covered by mosses, in the polar circle, almost exceeds belief. Sprengel states, that "in regions where the soil is never thawed beyond the depth of four inches, mosses and lichens are the only vegetable inhabitants, as has been proved by the relation of Sujef, who went, under the direction of Pallas, in 1771, to the coast of the Icy Sea. The northern border of Siberia, towards the coast of that Sea, is, for the width of some hundred versts, one continued morass, destitute of trees, where, in the middle of summer, the thaw never penetrates beyond a span deep; and here the whole soil is covered by mosses. In Spitzbergen, according to Martens, the rocks of Schistus, rising out of the everlasting masses of ice, are thickly clothed with mosses; and in Greenland they constitute the most numerous class of vegetables."

Throughout the whole of Scandinavia, mosses abound; and there, as well as on the Carpathian and Swiss Alps, in the Vosges in the woods of Thuringia, in Hercynia, new species, and even genera, are not unfrequently discovered.

In North America, mosses are at least equally abundant; but though, from the time of Dillenius, European botanists have had correspondents in the British settlements, the muscology of that continent is still very imperfectly known. The humidity of the southern parts of South America, and of Terra del Fuego, is equally favourable to mosses; and in these parts often large districts are completely covered with them. It is well known that Dillenius received a considerable number of his rarest species from Patagonia: and that thence Commerson brought home a rich collection belonging to this family. The riches of Terra del Fuego in mosses, is attested by Forster, who, however, did not collect any.

Nor are the islands of the Pacific Ocean, particularly the more southerly, less favourable to the growth of mosses. To them we owe that singular hepatic moss, Monoclea Forsteri, named by the discoverer, Mr. Forster, Anthoceros univalvis. The riches of New Zealand in this family, are proved by the collection brought home by Mr. Menzies. And, should the existence of the new Southern Continent, said to have been lately discovered, be verified, we cannot doubt that the botanist who shall first investigate that country, will obtain, with comparatively little trouble, a rich harvest of new species, and perhaps some new genera, belonging to this family.

In New Holland, the mosses differ as much from the mosses of other countries, as do the cotyledoneous plants. Instead of polytricha, we have that singular moss Dawsonia polytrichoides; instead of the usual forms of Gymnostomum, we have those peculiar mosses with a gibbous capsule, a membrane across the mouth, and a very peculiar habit, of which Mr. Brown has formed his genus Leptostomum. As yet the muscology of New Holland and its dependencies is extremely little known; and we doubt not that a rich harvest remains for any botanist that may have opportunity and zeal to investigate it further.

That Asia abounds in new species of mosses, and is by no means destitute of new genera, has of late been amply proved by remittances received in Europe. To Nepal we owe that singular moss Lyellia crispa, which has several points of affinity both with Dawsonia and Polytrichum; Calymperes Garneri; Octoblepharum serratum; Schlotheimia sulcata, besides a very considerable number of new species belonging to genera well known in Europe; all of which have been collected and transmitted by the Honourable Colonel Garner; another instance of the zeal of the Honourable East India Company's servants in the cause of science. That distinguished botanist, Dr. Wallich of the Calcutta gardens, has also transmitted to Europe a number of new and interesting species. But in Asia, still, as indeed in every country out of Europe hitherto mentioned, next to nothing has been done, compared with what remains to do.

The muscology of Africa seems to be more imperfectly known than that of any other country which has been trod by the foot of science. Nor is this wonderful, since we know so little of that continent itself. Yet it can scarcely be doubted that the high lands of Abyssinia, the summits of that lofty ridge termed the mountains of the moon, and of other lofty ridges, the banks of rivers, and the swamps, which are too plentiful and extensive for the health of Europeans on some parts of the coast, all abound in mosses.

Of the dependencies of Africa, the isle of Madagascar has a rich cotyledoneous flora, a rather humid soil, deep shady woods, and is somewhat mountainous. This island presents a very fair prospect to the muscologist.

Having thus taken a general view of the distribution of mosses over the globe, or rather of the very slight degree of knowledge which has been attained respecting this distribution, something may next be said of the particular localities which different mosses affect.

It has already been mentioned, that moisture and shade are favourable to the growth of mosses in general. These are peculiarly requisite for the hepatic mosses. Yet several species of mosses choose their residence where they have no shade, and comparatively little moisture. The four species of Andraea grow only on the dry sides of exposed alpine rocks; Grimmia saxicola delights in a similar situation, but sometimes descends somewhat lower. Anictangium ciliatum; Grimmia ovata, and pulvinata; various Trichostoma; delight also on exposed rocks and stones, receiving no moisture except from rains and dews; and hence their existence, like like that of many other mosses, is torpid for most of the summer. Tortula muralis abounds, as its specific name imports, on walls; has equally little moisture; and is also torpid during ordinary summers. Tortula ruralis, and subulata; Didymodon purpureum, and various Hypna which grow on thatched roofs and on turf-capt walls, (as well as in various other situations,) are equally destitute of moisture and shade with the species already mentioned. Diphyscium foliosum grows on the sides of dry rocks, or on dry knolls, and is in perfection in the latter months of autumn. Some mosses will thrive in a soil of pure sand, as Tortula ruralis, Hypnum lutescens, and perhaps H. dendroides. Buxbaumia aphylla delights in peat-moss, and will thrive in it whether it be dripping wet, or quite dry. Various mosses grow on fields and mountains, in situations not particularly either wet or dry, and having no shade but what is occasionally afforded them by the heath or grass among which they are situated. Such are Hypnum undulatum, loreum, splendens, schreberi; Didymodon purpureum; Bryum alpinum, and nutans, &c. On the other hand, many delight only in densely shaded, moist situations, and grow on the earth, or creep over other substances in their way; such are Hookeria lucens; Hypnum proliferum, praelongum, striatum, denticulatum triquetrum; Bryum roseum, &c. Various species must be considered as bog species; such are Weissia splachnoides, Hookeria lætevirens; Hypnum cuspidatum, cordifolium, filicinum, aduncum, scorpioides; Bryum palustre, dealbatum, ventricosum, punctatum, hornum. Dicranum glaucum, cerviculatum, and flexuosum, grow in bogs and other moist places; the four Sphagna also may be considered as bog plants, though Sph. obtusifolium, and Sph. acutifolium, oft grow on the mountains, merely in moist situations. Many species are fond of running water; such are Cinclidotus fontinaloides, the three species of Fontinalis, Bartramia fontana, Hypnum fluitans, ruscifolium, &c. Most of the elegant Splachna, obscene in their habitation, prefer the dung of animals, in alpine situations. Many mosses grow on trees; such are Gymnostomum viridissimum; Pterogonium smithii; Leucodon sciuroides; Zygodon conoideum; most of the Orthotricha; Neckera pumila; Hypnum trichomanoides, complanatum; occasionally, serpens curvatum, and myosuroides, &c.

The geognostic relations of mosses are too little known to have place in this brief sketch.

SYSTEMATIC ARRANGEMENT OF MOSSES.

This extensive family, or class, naturally subdivides into two orders, which were termed Musci frondosi, and Musci hepatici, by Hedwig. We reluctantly part with a term sanctioned by so great an authority, and more particularly as this arrangement of musci was first suggested by him: Yet we feel ourselves obliged to use the term foliosi, first proposed by Sir J. E. Smith, that we may avoid an *equivoque* between the order of Frondose musci and the frondose species and genera of the Hepatic musci. The two orders may also be termed, with much propriety, Plantae operculatae, and Pl. desperculatae, with Mohr.

ORDER I.

MUSCI FOLIOSI, OR OPERCULATI.

The Musci foliosi, or operculati, have the herb always divided into stems, roots, and leaves, and the fruit covered with a calyptra, and raised on a seta, or fruitstalk, except in the two genera Andraea and Sphagnum, in which it is sessile.

The capsule is always entire, except in Andraea, in which it is quadrivalve; and except in Phascum and Voitia, in which it is indehiscent, it opens by the separation, by a transverse line, of a part termed Operculum or lid, from the summit of the capsule.

The natural character of this order is to have the flowers monoecious, dioecious, sometimes united, or polygamous.

Male Flowers.—Calyx polyphyllous, the leaflets generally of the same colour with the leaves of the plant; but frequently different in form and texture; sometimes coloured; spreading when the flowers are discoid, conniving when they are budlike.

Corolla none. Stamens several, within a polyphyllous calyx, with succulent filaments intermingled; in some species they are aggregated into a capitulum, and raised on a stalk above the calyx; in others, they are scattered in the axillæ of the upper branches. Filament short (except in Sphagnum, in which it is somewhat elongated) filiform; anther roundish, ovate, or cylindrical, consisting of a mass of pollen, contained in a case that usually opens by a lid.

Female Flowers.—Calyx a perichaetium, many-leaved, the leaflets oft more delicate in texture than the other leaves, enclosing several pistils, with succulent threads intermingled among them.

Corolla none, unless we describe under this name the loose exterior covering of the capsule, which is cylindrical towards the base; terminates upwards in a cone; adheres at the summit to the capsule, and is free every where else, except (during the flower) at the base.

Pistil, cylindrical at the base, terminating above in a cone; the style elongated, slender, covered to the very summit by the calyptra. The stigma truncated or concave.

Pericarp, a capsule, entire except in Andræa; elevated on a fruitstalk, except in Sphagnum and Andræa; opening by the separation of an operculum, except in Phascum and Voitia, in which it is indehiscent; the mouth either naked, covered with a flat membrane, surmounted by a conical membrane, or by teeth, which are always definite in number, except in Dawsonia, and either in a single or double row; an elastic ring frequently present without the teeth; walls of the capsule always double, though in some instances very closely approximated; when the peristome is double, one row of teeth usually arises from the summit of each. An upright pillar, termed Columella, which rises perpendicularly from the base to the summit of the capsule, and sometimes, as in Systilium splachnoides, and Hypnum dendroides, continues attached to the operculum after the capsule is opened, is always present in this family.

Calyptra, torn by the elongation of the fruit-stalk, or by the enlargement of the capsule, either from the base, or by a nearly horizontal section about the middle; oft split at one side; in some instances very small and caducous; generally deciduous; very rarely persistent.

ANATOMY AND PHYSIOLOGY OF FOLIOSE OR OPERCULATE MOSSES.

Mosses appear to consist entirely of cellular texture, which varies much in density, and in the form of the cells in different species, and even in different parts of the same species. In the stems and nerves of the leaves, the cells are narrow and elongated, from the effect of pressure. In many instances, the compression and elongation of the cells takes place chiefly at the circumference of the stem; while those in the centre preserve very nearly their original hexagonal, pentagonal, or other, and frequently more complicated form; indicating that in mosses, as in palms, vegetation is most active in the centre of the trunk; while, from the ready and abundant ramification of a large proportion of species, this family has some analogy, in external aspect, to the dicotyledoneous vegetables. The elongated cells have been described by Hedwig, the first of Muscologists, as straight tubes, analogous to those figured by Grew and Malpighi, as a constituent part of the larger plants, and as forming, in particular, a great part of the wood of ligneous dycotyledons. But in the larger plants, these supposed tubes are now generally admitted to be merely condensed cellular substance; and in mosses, a gradation may be traced from the roundish, or angular and nearly equal-sided cell, to the tubiform appearance produced by elongation from pressure. Hedwig concluded, from analogy, that spiral tubes exist in mosses, and adduced the disengagement of globules of air, about the size of moss seeds, from dissected portions of the stem, while he was examining them under a microscope, and from the dry calyptra when placed in water, as proofs of their existence. But he admits that he had never been able to detect them by the knife and microscope; and his hypothesis, that pollen is formed chiefly by the agency of the spiral vessels, perhaps predisposed him to admit their existence upon slighter grounds than he might otherwise have considered necessary. The light which the researches of that distinguished investigator have diffused over the structure and economy of mosses, entitle even his opinions to great respect: and Bridel, without adducing any new fact, considers the existence of the vessels in question to be established; thinks that they form the chief part of the meshes that divide what are usually termed the cells of the leaves; and doubts whether "in these meshes the vessels form a single stratum only, or several strata superimposed, as in the leaves of the apple and orange." By means of these vessels, which he thinks traverse the whole structure of a moss, and by them alone, are we enabled to explain the transformation of a disciferous into a capsuliferous plant. But he does not show, in what manner these vessels would assist us in the solution of this difficulty. We are unable to see how it can be in any degree affected by the question about the presence or absence of spiral vessels, and think that it can be solved only by considering species which had been reckoned dioecious, to be really monoecious.

We distrust conclusions drawn from analogy, when the substances compared have so many points of discrepancy, as musci and cotyledoneous plants. The structure of the ridges that form the partitions between the cells, and of the slightly elevated lines that cross the cells in different directions, is at present altogether unknown. It may consist of a congeries of extremely minute tubes; analogy perhaps favours that supposition; and we recommend the inquiry, as one of no mean interest, to the vegetable anatomist, and to botanists in general.

In the flat part of the leaves, the cells are in general less compressed than in the stems and nerves, yet even in the leaves they vary exceedingly in form in different species, and sometimes not a little in the same species, at different periods of growth. Very frequently bars, much more slender than the parietes of the cells, traverse the cells in different directions, but chiefly in the direction of their narrowest diameter. These are very conspicuous in the genus Sphagnum, in which the cells are of a very peculiar form; and they are more or less visible, crossing the cells of most mosses. In Hookeria lucens the cells are of a rhomboidal form, the diameter between the angles pointing from the base to the apex of the leaf, being about twice as long as the transverse one. In Diphysicum foliosum the cells appear somewhat like small irregluar openings in a very dense texture. And almost every moss has something peculiar in the form of its cells.

No pores have hitherto been traced on the surface of any moss; and neither pores, nor any other means of communication, has been traced in the interior between the cells. Yet it is certain that they are extremely permeable, and that they imbibe water with great avidity, not merely when in a state of active vegetation, but after they have been preserved dry for several years. A dried moss may thus, after having been preserved for any number of years, at any time be restored to its original verdure, and to the exact appearance which it had when growing, by simple immersion for a few minutes in water. There is, however, one case of exception. If, in the original drying, great pressure, or the smoothing iron has been used, for the purpose of making very showy specimens, then the original form can never be regained. Of course, if one set of these fine specimens be kept for show, there should be others, less artificially prepared, for use. It is remarkable, that a moss which has been, from drought, quite arid, and in a state of torpor for several months, or even for years, will, in many instances at least, on the re-application of moisture, grow as vigorously as before the commencement of the torpidity. But mosses that have been deprived of vitality by heat, or by whatever other means, imbibe moisture when dry, as rapidly as mosses merely torpid. It appears, then, that this quality of absorption in them is not dependent, or at least not always dependent, on the vital principle. May it not, then, be, at least in the dead moss, the result of a chemical affinity between water, and that modification of vegetable matter of which a moss is composed?

In regard to duration, mosses may be divided into annual, biennial, and perennial.

The particular parts of mosses may be divided into conservative and reproductive organs.

CHAP. I.

CONSERVATIVE ORGANS.

These may be conveniently subdivided into roots, stems, branches, and leaves.

Sect. I. *Of Roots.*

The root, that part by which the plant is fixed and nourished, can scarcely be said to be wanting in any plant, at least, certainly, not in any moss: And both the species into which roots are usually subdivided—the primary and secondary—are exemplified in this family.

The primary root, that sort which is analogous to the prolongation of the rostellum in the cotyledoneous tribes, is sufficiently obvious in a young moss, though the mode of its original evolution seems to be considerably different from that of cotyledoneous plants. Like what are usually called the cotyledons, it seems to be a mere expansion of the substance of the seed itself, the stem soon after appearing exactly opposite it. In Buxbaumia aphylla, it persists, and is curiously divided, almost immediately below its origin. It is thicker than the secondary roots; but in Sphagnum, in Hypnum, with its affinities, with few exceptions, and indeed in the greater part of the family of mosses, the primary root is of no long duration, being, with the lower part of the stem itself, choked by the exclusion of air, owing to the luxuriant vegetation of the parts above it: it soon decays, and forms mould. The plant is then nourished by the secondary roots, which shoot in profusion from every part of the stem, particularly from its under side, if in contact with a moist surface. They arise first from the axils of the leaves; but in several species they soon cover the whole of the stem towards the lower part with a dense woolly tomentum, which, in bog or water species, as in Bryum palustre, Bartramia fontana, is usually dark brown, and often becomes long and crisp, concealing not merely the stem between the leaves, but ultimately choking the leaves themselves. In several species roots arise also from the nerves of the leaves. In Timmia megapolitana they have been observed to originate from the nerve, after the flat part of the leaf had decayed. In nerveless leaves, they sometimes arise from the apex, and even from the *flat expanded disk*, (an origin which we have not found anywhere noted,) as in Hookeria lucens.

Whether primary or secondary, they are always fibrous; and though simple, when protruded, soon become divided or branched. In an early state, they appear like undivided tubes; but they soon become opaque, and when examined by dissection, are found to be divided into cells by transverse partitions. Externally their colour varies, from white, which is rare, unless in an early state, through various shades of brown to black.

Sect. II. *Of the Stem and Branches.*

Nor is the stem ever wanting in the structure of a moss, though in some species, as in Diphysicum foliosum, Weissia nuda, some Phasca, and even some Gymnostoma, it is not very obvious at first without a magnifier, appearing little else than a thin plate interposed between the roots and the fructification. In Buxbaumia aphylla it is in the form of a bulb. It is usually cylindrical; yet in Bryum cuspidatum, ligulatum, and some other species with decurrent leaves, it appears angular. When sterile it usually tapers to a point, but in the fertile state it is frequently club-shaped; and though solid in the other parts, (excepting in the base of the bulb of Buxbaumia aphylla, which is hollow, at least in the young state,) these club-shaped extremities are not unfrequently found hollow. Even these stems or branches, however, were originally tapering like the others; and it is not till after the stem or branch has attained its full length, that the incrassated club-like extremity begins to be formed. On a transverse section of it we usually find the appearance of a division into epidermis, bark, wood, and pith; appearances which seem to be owing entirely to the form and size of the cells, occasioned by some difference in the degree of pressure to which the different parts have been subjected, and the length of time during which it has been continued; or, at least, not to require for their explanation any other cause than different modifications of the same cellular tissue, by whatever means produced. We have not been able to find in these stems the "vasculosum opus," mentioned by Hedwig; we have found no proofs of its existence that are satisfactory, adduced by others, and hence we must, in the mean time, consider its existence as hypothetical.

The surface of the stem is either quite smooth, or it is roughened with papillæform excrescences; perhaps never downy, though it often appears so, from being covered with minute roots. At the lower part, and in the thickly branched species, not unfrequently throughout a great part of the length of the stem, as in various Hypna, it often appears scaly, from the remains of decayed leaves. In duration, it is in some species annual or biennial; in which instances it continues always soft and succulent; but in the greater number of species it is perennial, and oft acquires somewhat of a woody consistency. In direction it is upright, the stem by its rigidity supporting itself, as in Hypnum dendroides, Bryum ligulatum, and other analogous species, in which the tap root persists; in other instances, the stems, though weak, support each other in an upright posture, in consequence of growing in thick tufts, as in some of the Sphagna; or it is always recumbent, as in most of the Hypna Neckeræ, various Dicrana, &c. Many of these procumbent species may be said to be creeping, because they protrude roots from the whole of their under surface. Many species, particularly those of short duration, have the stem quite simple; but some, even of the annual species, are branched, as are perhaps all the perennial species, without exception, either simply or repeatedly, bifariously or irregularly;—in short, exhibiting a very considerable variety of modes of ramification. After the flower, it is not uncommon for the species truly simple, at the time of flowering, to produce either one or two branches from the extremity of the stem, on one side, or on two opposite sides of the young fruit; and thus the mature fruit, in some instances, acquires the appearance of being lateral, or axillary, though the flower was terminal. In the species truly branched, innovations, as the terminal prolongations are named, also have place, besides the branches arising variously, determinately, or indeterminately, along the sides of the stem, and in these species the flowers and fruit occur exclusively, or almost exclusively, on the branches.

SECT. III. *Of the Leaves.*

No species of operculate or foliose moss is leafless; though the specific name of Buxbaumia aphylla, is a proof that it had once been considered as an instance.

As in other plants, the leaves of mosses may be said to be radical, cauline, rameal, or floral, according to the parts of the plant on which they grow, or which they surround.

In no species are they pedunculate, in general they are simply sessile; yet in many species they are amplexicaul, in others decurrent. In the plants with male flowers of Dicranum bryoides, they may be said to be sheathing, the upper and inner side of the leaf being double towards the base, the folds arising on opposite sides of the stem —a structure having a remote affinity to that of the lobulate Jungermanniæ.

In every instance the substance of the leaf is continuous with that of the stem; a leaf truly deciduous, which separates by an articulation, being unknown in the family. They always persist; and often long after they have been decomposed in the place where they grow, the remaining nerve or fragments of the base of the leaf show where they had been inserted. They never occur opposite or verticillated, but are always in alternate order. In insertion they are either bifarious, as in a section of Dicrana, Hypna, various Neckeræ, &c.; trifarious in Fontinalis antipyretica, and Bryum triquetrum; quadrifarious, as in Hookeria lucens, though their summits are directed bifariously; in six rows, in Hypnum triquetrum. In most mosses they arise indiscriminately from every side of the stem; either distant, or in close array; and are, in the direction of the leaf, either imbricate, patent, squarrose, or secund. In many instances the disk of the leaf is concave, in others it is recurved; in Fontinalis antipyretica, it is complicato-carinate; it is seldom quite plain.

Except in the Buxbaumia aphylla, in which the leaves are deeply laciniate, they may be said to be entire;—though in the only known species of Diphyscium, and in some species of Anictangium, the perichætical leaves are divided into an indefinite number of long slender segments. In form they vary very much, being cordate, roundish, ovate, obovate, oval, linear, subulate, strap-shaped, &c. The sterile plants of Shistostega pinnatâ, (or Gymnostomum pinnatum,) resemble a frond, the bifarious leaves being confluent at the base. In most instances, the leaves are furnished with a nerve, which either projects beyond the summit, forming a hairlike point, or terminates exactly at the apex, or at a less or greater distance below it. In some instances, when the nerve terminates below the summit, it becomes forked. It sometimes occupies a great part of the disk of the leaf, as in some Dicrana, and in Bartramia ithyphylla. In the latter species it disappears about the middle, blending with the substance of the disk of the leaf. When there are two nerves, in no instance do they reach the summit of the leaf. In Hookeria lacte-virens alone, they proceed pretty near it. In general they do not proceed beyond the middle of the leaf; and sometimes only for a very little way above its base. The margin is generally simple, not differing in substance or in texture from the disk; yet sometimes, as in certain Gymnostoma, and a section of Bryum, it is very evidently incrassated. In either case, it may be quite entire, serrate, crenate, or ciliate. When it is serrate, the nerve also, in some species, particularly toward the summit, is marked with the same serratures; and in Polytrichum undulatum, they occur over a considerable part of the under surface of the disk, towards the summit. The serratures, in many instances, extend along the whole free margin of the leaf; in other instances, only for a certain distance from the apex.

The surface of the leaves is in general quite smooth, and often shining. The under side of the leaf is roughened with numerous projecting points, in Anictangium ciliatum, Hypnum proliferum, and some others. In various Hypna, both with and without a nerve, the leaf is traversed longitudinally by various stripes; and in some Neckeræ, in Hypnum rugosum, Dicranum undulatum, &c. it is transversely wrinkled.

In structure the leaves of the mosses consist of cellular tissue, inclosed in epidermis. In the meshes of the cellular tissue is contained, perhaps in every instance except the Sphagna, and Dicranum glaucum, a very succulent pulp. In Sphagnum, they contain only a nearly limpid juice. If a leaf be cut across, and quickly placed under the microscope, the sap may be seen flowing, by the sides of the meshes, in little currents, out of the cells. Hedwig, who first made this observation, describes the sap as flowing out of the meshes or partitions themselves, by which the cells are divided. In repeating his experiment, the little current has always appeared to us to flow by the sides of the meshes; and in some instances, to be wider than the diameter of the partition itself; and hence we are unable at present to admit these currents as a proof of the vascular structure of the leaf, although we should have been much delighted, by perceiving sufficient proof, anywhere, of this supposed vascular structure of the leaves, as well as of the supposed vascular structure of the stem.

CHAP. II.

OF THE REPRODUCTIVE ORGANS OF FOLIOSE MUSCI.

SECT. I. *Of the Flower and Fruit.*

THE flowers of mosses are in most instances monœcious; in a considerable number are they diœcious; very rarely are they polygamous (Bryum palustre); and equally rarely are they bisexual or united (Bartramia pomiformis, Bryum trichodes.)

Mosses in general are fond of growing in tufts, particularly the diclinous species. So closely are the male and female plants of Gymnostomum pyriforme frequently placed together, that, on a cursory view, they may appear to spring from the same root.

In regard to situation, the flowers of mosses arise either from the base of the stem, from its apex, along its sides; or from the apex or sides of the branches. To give instances of some of these modes of distribution: In Dicranum taxifolium the female flowers arise from the root; the male are axillary. In the genus Phascum, the female flowers are terminal, the male (usually very minute,) are axillary. In Hypnum triquetrum, a diœcious species, the male flowers appear chiefly on the sides of the branches, the female on the sides of the stem. In H. proliferum, both male and female flowers grow from the sides of the stem. In the genus Sphagnum, the male flowers are found in the incrassated apices of the upper branches, the female are axillary.

Though the flowers of mosses are minute, they may, with few exceptions, be easily discovered by an eye somewhat practised, either without any assistance, or with the aid of a common pocket glass.

The flowers of mosses, as of other plants, consist of the essential parts of fructification, and their envelopes.

The envelope of the flowers of a moss is termed Perichætium. It is usually polyphyllous. but the male flowers of Encalypta vulgaris, and a few other species, have a four-leaved perichætium. The number of leaves in the perichætium of different species, varies from six to twenty. The perichætial leaves are seldom in a single row. When in several rows, the outermost are usually smaller than the intermediate, and the innermost are the smallest. Except in some few instances, in which those surrounding the female flowers are similar to those of the stem, the intermediate and inner, (and sometimes also the outer perichætial leaves) almost invariably differ very much in structure, form, and sometimes in colour and margin, from those of the stem. Thus in Encalypta vulgaris, and ciliata, the perichætial leaves want the very prominent nerve of the stem leaves, and are altogether unlike them in form. Peculiarities in the perichætial leaves of Dicranum bryoides, and Diphyscium foliosum, have already been mentioned; and it may now be added, that while the interior perichætial leaves in Diphyscium foliosum divide at the summit into cilia, the exterior are acuminate, and the stem leaves are tongue-shaped. It would appear, also, that in Buxbaumia aphylla the leaves are of two different sorts. Those with which we have been for some time acquainted, and of which we examined a very considerable number in October, 1819, are reticulated, the cells usually hexagonal or oval; much more rarely, we conceive, oblong, as they are represented in Mr. Greville's accompanying figure. The other sort, which we conceive to be perichætial leaves, were discovered by Mr. Greville, while he was drawing the figures for this paper. They have the appearance of a number of conferva-like filaments, united in a single file. These leaves, like the others, are laciniated; and the laciniæ are formed by the separation of the filaments into sets of two or three; and sometimes a single one goes to the formation of a segment by itself In the laciniæ, the filaments sometimes again separate towards the summit. With these leaves we are quite unacquainted; but we can rely on Mr. Greville's accuracy. The Hypna in general have the female flowers surrounded by a perichætium consisting of membranaceous, transparent leaves, extremely different from those of the stem.

The male and female flowers of mosses may in general be distinguished without much difficulty, even without opening the perichætial leaves. The male flowers, when axillary, are more rounded at the base; are shorter, and have an appearance of greater firmness and compactness than the axillary female flowers. When the flowers of the one sort are axillary, and of the other termenal, there can be no difficulty; yet even then oft the same distinctive marks prevail.

The essential parts of the flower consists of stamens and pistils.

The stamens, as already mentioned, usually occupy a separate flower from the pistils. They are always numerous in the same flower. They consist of a filament, usually short, but in Sphagnum of considerable length, and a mass of pollen similar to that of the Asclepiadeæ, contained in a double membrane, situated upon it. The form of this mass is usually cylindrical; but in the genus Sphagnum, and in Bryum androgynum, it is ovate, and somewhat acuminated. In Sphagnum, it appears to be surrounded, in the perpendicular direction, by a ring. The membrane containing the mass of pollen never separates from the filament, unless owing to external violence. Its colour is in every instance a light green.

If placed in a drop of water in a concave glass, the colour becomes lighter, it enlarges; and when its contents are about to be emitted, it is nearly pellucid. At last it opens at the summit, either irregularly, as in Sphagnum, or by a sort of lid, as in most other mosses, and emits, with force, a transparent viscid fluid, with numerous coloured granules intermingled. Afterwards, the empty exterior of the mass shrinks; it becomes divided into large reticulations; its colour becomes yellowish, and at last its sides fall together.

This process may easily be observed also, without the aid of water. The figure of it given by Hedwig, in *Theor. Generat. et Fructif. Plant. Crypt.* t. xi. was taken in the dry state, under the solar microscope.

This is the account given by Hedwig in the second edition of the work just alluded to, (Leipsiæ, 1798,) and which has now approved itself to the botanical world in general. In the former edition of the same work, and in his other previous writings, Hedwig described mosses as possessing true anthers or bags containing a *dry* pollen, and even figured repeatedly the pollen in the act of escaping. But subsequent and more accurate observation convinced him that this was a mistake.

Generally, in both male and female flowers of mosses, occur a great number of succulent jointed threads. In some species they retain the same thickness from the base to the summit, and terminate acutely or obtusely; in others they swell towards the summit into various forms. In Dicranum pellucidum, they are slightly club-shaped, in Bryum triquetrum, very evidently so. They terminate in incrassated globular joints in Bartramia fontana, Bryum punctatum. After becoming club-shaped, the last joint forms an apiculus in Bryum hornum; in Funaria hygrometrica, they vary in form. The threads, however, which are thus incrassated towards the summit, occur only in some terminal male flowers, and never in those that are axillary. In a few rare instances, the threads are altogether wanting, as in the male flowers of Grimmia pulvinata. When present, they are compared by Hedwig to the nectaries of other flowers, affording a moist halitus, well fitted to promote the emission of the fluid, which constitutes most of the mass of pollen.

The pistils of mosses, with a few rare exceptions, among which is the genus Sphagnum, always occur several together in the same flower. In Sphagnum they are solitary. In the female flowers of Diphyscium foliosum, six pistils always occur; in Encalypta ciliata, and Dicranum bryoides, seven; in Encalypta vulgaris, ten; and in Bryum hornum, twenty. But of these, in general, only one becomes fruit-bearing; the rest soon wither, though they persist. Yet in Bryum ligulatum and punctatum, Dicranum scoparium, and some other species, we frequently find several capsules arising from the same perichætium. The sterile pistils, being at first supposed by Hedwig to be of no other use than to assist the fecundation of the fertile one, by making the flowers larger, and thus favouring the ingress of pollen, were at that time named by him adductors. But he afterwards renounced this idea; considered all the pistils as equally susceptible of fecundation; and the use of so many in a flower to be, that at least one capsule from it might be secured. They consist always of three parts, the stigma, style, and germen.

In its younger state, the stigma appears closed and convex. At maturity it opens, and becomes cup-shaped; and a granular matter is sometimes seen to arise from it, the nature and use of which is quite unknown. As the stigma opens, the style begins to show in some species a single canal, as in the genus Sphagnum, in Encalypta vulgaris and ciliata; two canals, as in Gymnostomum truncatulum; several, as in Hypnum triquetrum. They are sometimes furnished with lateral bars, resembling plaits in the surrounding membrane. The style is generally deciduous, in some few instances it is caducous.

The germen is at first usually of a figure more or less ovate, generally acuminate towards the summit; when it begins to swell, it assumes the figure of a cone.

Objectors to the Hedwigian theory have contended, that it is scarce possible to conceive that the pollen, from a close gemmiform separate flower, should ever reach the pistils, even in monœcious mosses. They have considered the objection still stronger in the case of the diœcious, and altogether insuperable in regard to the aquatic species. But since the fluid contained in the mass of pollen escapes with a very considerable elastic force, there seems no reason to doubt that it may easily clear the leaves of the perichætium; and besides, these at certain times open very considerably. The diœcious species usually live in society, the males intermingled with the females. But in cases where clumps of male or female mosses occur at a distance from the other sex, even this can be no more a legitimate objection to the Hedwigian theory, than the occurrence of male or female date-palms, at a distance from the other sex, can furnish a legitimate objection to the sexual theory in Phaenogamous botany. In such instances, the plants, on examination, have invariably been found sterile. The objection respecting the aquatic mosses will appear by no means formidable, if we recollect, that in serene weather, the young flowering branches of Fontinalis antipyretica may be found floating on the surface of the water, while in rainy and cold weather they seek the bottom; and that of other aquatic mosses, which have not this habit, or the stems of which are too short to reach the surface of the water, perhaps all are sterile, unless when they grow in places only occasionally inundated. For further objections to the Hedwigian theory, we refer to Gaertner *De Fructibus et Seminibus Plantarum*, in the *Introduction*; *Neckar's Physiologia Muscorum*, and *Methodus Muscorum*; and to *De Beauvois' Prodrome d'Aetheogamie*. The objections of these writers, we have no doubt our readers will find no difficulty in answering for themselves. Those of Gaertner, in particular, have been generally noted as quite unworthy of so great a man. His remarks, made at a time when the pollen of mosses was supposed to be farinaceous, regarding the effects of moisture on the pollen of mosses, in particular, show that his love of argument, in this instance, had made him forget the nature of pollen, in the whole division of cotyledoneous plants.

In the female flowers, the succulent jointed threads, mentioned under the male flowers, are also very rarely absent. In various Polytrichia, they are so abundant, that, adhering to the glutinous calyptra, when it is rising, they furnish it with a dense hair-like covering. In these mosses, the threads are always filiform throughout.

The calyptra is a thin transparent membrane, that completely invests the pistil. Around the germen it is always free; though at an early period it embraces the germen so closely as to have the appearance of cohering with it. It forms the transparent exterior covering of the style, and is inseparably connected with the little ducts in the centre. Of the stigma it forms the chief part of the large cup-shaped expansion. After fecundation, the calyptra is the first part which begins to enlarge. The style and stigma are not long in decaying; but the part of the calyptra surrounding the germen becomes ventricose, (in Gymnostomum pyriforme) sometimes flagon-shaped, (in Funaria hygrometrica) sometimes it is constricted in the middle, (as in the genus Sphagnum;) and in every instance, in this state, it contains a limpid fluid. The fruit stalk begins to elongate; but the fruit remains extremely small in the upper part of the Calyptra. After the Calyptra has been torn up from the base, by the elongation of the fruitstalk, then the fruit, having more freedom, begins slowly to enlarge. In the genera Sphagnum and Andraea alone, in which the capsule is always sessile, the calyptra is, by the enlargement of the capsule, torn irregularly towards the middle; and the upper part is very fugacious.

The calyptra, when torn from the receptacle, is in some instances quite entire at its base, and not in the least cleft in any part, as in Encalypta vulgaris, in which moss, and in the whole genus, it completely encloses the mature fruit. In other instances it is mitriform, being smaller than in the Encalyptae, and having an indefinite number of clefts, of no great depth, situated all around the base. In other instances it is dimidiate (cucullate, or hood-shaped, as some term it) when it is split from the base on one side, for about two thirds or more of its depth, throughout the whole of that part which covers the capsule, excepting that in which the beak of the operculum is situated. When dimidiate, it is in general situated more or less obliquely upon the capsule; when mitriform or campanulate, it is situated straight. In exterior, it is either quite smooth, as in Polytrichum undulatum, the Encalyptae, the Hypna, or at least most of them, &c. or sparse hairs project uprightly from it, as in the Orthotricha; or it is furnished with a dense covering of hairs, not attached to it, except laterally, which are merely the succulent filaments which had adhered to it when it began to rise, in consequence of a glutinous exudation, as in many Polytricha, and in the genus Dawsonia. The true Calyptra of the hairy Polytricha is very small. In general, the Calyptra falls some time before the separation of the operculum, or lid of the Capsule. But in Encalypta vulgaris, and ciliata, Tetraphis pellucida, and some others, it persists till the time when the operculum separates.

The chief purpose of the flower of mosses, as of other plants, is the formation of the fruit.

The fruit of mosses is always capsular, and is always furnished with an operculum or lid, situated at the summit of the capsule. For a considerable time before the maturity of the capsule, the difference in colour of the operculum, and the appearance of its margin, show that it is to separate by a horizontal line. Yet in three genera, Phascum, Voitia, and Andraea, it never separates; Phascum and Voitia having no regular mode of opening, and Andraea being the only genus of mosses known that has a valvular capsule.

In all other mosses the operculum separates at the maturity of the fruit, and discloses the mouth of the capsule, which is either quite naked, as in Sphagnum; covered with a horizontal membrane, as in some Gymnostoma, in Leptostomum of Mr. Brown, in Drepanophyllum, in Lyellia; surrounded by a plaited conical truncate membrane, as in Diphyscium; or by a toothed or ciliated process, or by both. The teeth are always definite in number, and, except in Dawsonia, the cilia also. The lowest number of teeth is four, in Tetraphis; the next eight, doubled, Otoblepharum, Fabronia and Splachnum; next 16, which are either entire and equidistant, as in Weissia, Calymperes, Grimmia; or cleft half way down from the summit, as in Dicranum; or cleft to the very base, or nearly so, in which case they may also be described as 32, placed in pairs, as in Didymodon, Trichostomum. We find next in Tortula 32 filiform twisted teeth, which are united at the base more or less into a tube. In Tayloria splachnoides are found 32 teeth in pairs, arising within and below the mouth of the capsule, curiously folded inwards when the capsule is moist, twisting outwards, in a singular manner, with a vermicular motion, on the application of drought or heat. The teeth of all mosses indeed have a certain degree of motion. They all expand on the falling of the operculum, and return to their position across the mouth of the capsule in moist weather. But the teeth of no other known moss have the variety, or rapidity of motion, of Tayloria. In Polytrychum the number of teeth is in some species 32, in others 64; in all they are united at the summit by a horizontal membrane. Of mosses with a double peristome, some have the cilia (as the divisions of the inner peristome are termed,) unconnected at the base; as in Funaria, Zygodon, Orthotrichum; others have them connected at the base by a membrane; as in Bartramia, Hookeria, Hypnum, Bryum. Fontinalis has for internal peristome, a reticulated cone; and Buxbaumia, a plicate, membranous truncated cone. The mosses having a double peristome have invariably 16 teeth, and in general, an equal number of cilia. Some species of Orthotrichum are irregular, in O. anomalum, and O. cupulatum, cilia being altogether wanting; in O. crispum, O. Hutchinsiæ, and O. affine, only eight being present. In some species of Hypnum and Bryum, filiform processes occur between the cilia. In Dawsonia alone the cilia are innumerable, and arise equally from the walls of the capsule, and from the central pillar termed Columella. This moss is quite unfurnished with teeth.

In several species of moss, around the teeth is situated an elastic ring; the untwisting of which, at the maturity of the capsule, assists materially in the disengagement of the operculum.

The walls of the capsule are double, and frequently, at its maturity, a considerable interval is interposed between them; yet in several species they occur always in such close proximity, as, on a cursory view, to appear but a single wall. The exterior is hard, crustaceous, and densely reticulated; the interior is much more delicate. The teeth of the peristome always originate in the outer wall; the cilia, the horizontal, and the conical membrane from the inner. The operculum seems also to be originally a mere continuation of the outer wall.

In form the capsule varies very much. It is roundish in Bartramia; pear-shaped in Funaria hygrometrica; subulate in Tortula; gibbous, or roundish on one side and flat on the other, in Diphyscium and Buxbaumia; quadrangular in some Polytricha, &c.

In direction, the capsule is either upright, and equal on every side, as in Gymnostomum (excluding Mr. Brown's Leptostomum,) Orthotrichum, Sclotheimia, &c. or as it is more or less inclined (cernuous) when the dimension of the upper side is usually greater than that of the lower; as in most Hypna, many Dicrana, &c. When inclined, it is sometimes furnished with a little mamilliform appendage towards the base, termed Struma, as in Dicranum virens, strumiferum, &c.

In colour the capsule varies very considerably, though this character has not hitherto been found of much consequence. Yet it is very striking in some foreign mosses; it is yellow, for instance, in Gymnostomum zanthocarpum; in Dicranum flexifolium and Drepanophyllum fulvum, it is of a brownish-yellow; in Calymperes Garneri it is of a reddish-brown, &c.

From the base of the capsule to its apex, arises an upright little pillar, termed Columnula, or Columella. This is universally present in the fruit of mosses. Its apex is considered by Hedwig as being always attached to the highest part of the interior of the operculum. In Buxbaumia aphylla it is narrow at the base, becomes ventricose towards the middle, and narrower again towards the summit. It is curiously bent as it passes from the inner wall of the capsule towards the apophysis. In this moss, at least in its younger state, the lower parts of the columella is hollow. In Gymnostomum pyriforme, it appears as if attached to the base of the capsule by a number of roots; and in the upper part assumes the forms of a drinking glass. In the genus Sphagnum, it is an obtuse cone.

Sometimes, as in Systilium splachnoides, and Hypnum dendroides, it remains attached to the operculum after the opening of the capsule. In the latter mentioned species, by contracting upon itself, it shuts the capsule by bringing down the operculum close upon its mouth, in moist weather, and raises it again when the weather becomes dry. Its summit is club-shaped, in Tayloria splachnoides, in Lyellia, at maturity, it seems to be terminated by the horizontal membrane, of which a part adheres to it; in Dawsonia, it terminates in numerous cilia. The use of this part is supposed by Hedwig to be, to promote the circulation of the juices of the capsule in its early state, and afterwards, probably, it adds to its firmness.

The capsule is supported on a peculiar elongated receptacle termed Seta, or Fruitstalk, which is produced after the flower. It is wanting only, as already mentioned, in Sphagnum and Andraea, in which the capsule is sessile. It is very short in Diphyscium foliosum, in most species of Phascum, in Grimmia apocarpa and maritima, in Cinclidotus fontinaloides, in the genus Fontinalis, &c. in which the capsule does not rise above the perichætial leaves. Usually the capsule is very considerably elevated above them. In Bryum riquetrum it is very long, reaching to three, or even five inches above the leaves.

The fruitstalk varies very considerably in colour. Its surface is generally smooth; but it is covered with papillæform excrescences, in Buxbaumia aphylla, Hypnum rutabulum, velutinum, lutescens, &c. At the summit, in several instances, it expands considerably, forming a part termed Apophysis. This part is small compared with the capsule, in those Polytricha that are furnished with it. In Tayloria it is long and narrow. Of all genera hitherto known, it is most remarkable in Splachnum, in some species of which, it is several times larger than the capsule itself, and is usually of a different colour both from the capsule and the fruitstalk. In Splachnum Sphæricum the apophysis is from twice to three times larger than the capsule; in Splachnum rubrum and luteum, it is umbrella-shaped; and the capsule appears merely like the top, or little ornament, above the umbrella. In the former of these two fine foreign species, the apophysis is of a deep red, in the latter, of a brilliant yellow.

Of the Seeds of Mosses.

The seeds of mosses vary very much in surface, in size, in figure, and in colour. In surface, the greater part of them are quite smooth and round, yet some are angular—the seeds, for instance, of Phascum serratum; some are marked with circular depressions, as in Encalypta vulgaris; some are echinated, as in Gymnostomum pyriforme, Bartramia pomiformis, &c. In size, it is remarkable, that, as in cotyledoneous plants, some of the minute species have much larger seeds than species of larger growth. Thus, in Phascum serratum, the minutest of mosses, the capsules of which contain 100 seeds, the seeds are larger in proportion than those of all the other Phasca, with the single exception of Phascum alternifolium, which contains sixteen very large seeds in each capsule. Similar variations in size occur in other genera. In figure, the seeds of most mosses are spherical, or approach to that form; yet in Phascum serratum an instance has been given of angular seeds, and in a considerable number of species, they are more or less oval. In colour, at first shades of yellow and green prevail in the seeds of mosses, afterwards of brown, but in both states the colour is subject to diversities.

The seeds of mosses are so minute, that their structure can be well investigated only in the process of germination.

Meese, in 1767, was the first to raise mosses from the seed. His experiments were made upon Polytrichum commune; but far more satisfactory experiments, and, indeed, experiments altogether conclusive, are those of Hedwig himself.

He seems to have been led to these experiments from an occurrence in May 1774. To a strong north wind for a night and day, succeeded cloudy, wet, and cold weather. In a few days afterwards, the earth in the flower-pots in his windows looking to the east, assumed a greenish hue. He conjectured this to be owing to young plants of mosses. Taking up some of them on the point of a penknife, cleansing them in a few drops of water from the adhering earth, and subjecting them to his microscope, he observed a young plant, with pellucid, very white roots, and above them some minute threads, delicately articulated in some parts. These threads he conjectured to be cotyledons, and immediately began to think of experiments for ascertaining farther this point. The species which he selected for this purpose was Funaria hygrometrica. Remembering that Dillenius states it to love arid and adust places, he made a soil for it, in a flower-pot, above common earth, of about an inch thick of ashes and charcoal intermingled, adding a very little earth to the composition. Over this he opened, with the point of a needle, several capsules of Funaria hygrometrica, the seeds being dispersed in little heaps. The seeds of other capsules, opened in the same manner, he scattered more equally over the flower-pot. That the seeds might not be blown away by the winds, he covered the flower-pot with well-washed branches of boxwood, and placed the flower-pot in one of his windows with a northern exposure.

In the first days after the sowing the yellowish heaps contracted a darker colour. Afterwards they could scarcely be seen by the unassisted eye. But on the seventh day from sowing, with the help of a moderately magnifying glass, he found the whole surface of the pot, and particularly the little heaps, of a greenish colour. The branches of boxwood were now taken away, and, having taken up some plants on the point of a needle, washed them, and placed them under his microscope in a drop of water, he saw with much pleasure, swimming in it, innumerable seeds, part of which had already produced a simple, very tender, pellucid, white root, and immediately opposite a simple obtuse corpuscle, of a very light green.

Three days afterwards, or on the tenth day, the whole surface of the flower-pot was covered with an agreeable green colour, and the little heaps had acquired a silky lustre. He now found the radicles increased either in number or by ramification; and the cotyledons branched. Eight days afterwards, there was no change, except that the whole was of a more intense green, and afterwards he perceived the leaves springing here and there.

The plants grew so rapidly, that in the month of October following, numerous disciform male plants appeared intermingled with very minute females. The latter having attained their proper size by the end of November, then protruded the stigma beyond the leaves of the perichætium; and in the following spring capsules were obtained from them, from which more young plants were obtained.

Similar experiments were afterwards made with Gymnostomum pyriforme, Bryum trichodes, and caespitium, and all with the same success. Similar experiments have since been made by several botanists, and all have since been satisfied of the truth of Hedwig's positions regarding the seed, with the exception of the late ingenious De Beauvois, who contended that what Hedwig and every body but himself called seeds was really pollen, and that the true seeds were to be found in the Columella. His hypothesis has been ably refuted by Mr. Brown, in vol. x. of the *Linn. Trans.*; who shows, that what De Beauvois took for seeds, were merely some particles of what he calls the pollen, which had been carried into the cellular substance of the columella by the knife.

Unfortunately the limits within which this paper must be circumscribed, will not admit of our entering upon our reasons for considering the supposed cotyledons as a peculiar production. But we appeal to observation, whether they be natural divisions of the seeds, or whether they be not mere growths from it.

SECT. II. *Of Gemmæ, or Buds.*

These are roundish or oval bodies, situated either in the axils of the leaves, or sometimes in the stellated extremities of the plants. They are totally different in structure from the anthera, never opening spontaneously, never containing a clear fluid, and they are never situated on a foot-stalk. When full grown, like the bulbs of the tyger lily, they fall off, and produce a plant similar in every respect to that on which they grew; but this is a mere lateral extension of the life of the individual, as in the case of a sucker, a graft, or a layer, and not the commencement of the existence of a new being, as in a plant raised from the seed.

We shall close this chapter with a brief sketch of different hypotheses respecting the flowers and fruit of mosses.

Micheli, who first investigated the flowers of mosses, considered the male as united, or bisexual flowers. The stamens he took for pistils, and the jointed threads for stamens; and the capsules he considered as another sort of fruit. Dillenius mistook the male for the female flowers, and the female for the male, and misled Linnæus. Hill considered the male flowers to be mere collections of buds; the capsule he considered as a united flower, the seeds being each a pistil, and the teeth being stamens,—a theory refuted by the toothless species. Meese adopted the opinion of Micheli in regard to the male flower, and of Hill in regard to the capsule. Koelreuter modified Hill's system, considering the calyptra to be the stamen, and not the teeth. Gaertner, like Meese and Koelreuter, speaks of the capsule as a united flower, but supposes the operculum to be the stamen. De Beauvois, as already mentioned, took the capsule for a united flower, the seeds for pollen, and the true seeds, he said, were contained in the columella. He most extraordinarily considered the seeds to be fecundated at the time of emission, the teeth, according to him, materially aiding the fecundation by their motion. Lastly, Neckar may be mentioned, (though he was contemporary with Hedwig,) who sets out with informing us, that he will never allow any of the cryptogamic plants of Linnæus to be endowed with sex; and then gravely states that mosses are propagated by buds, which he calls bisemenses steriles.

Generic Distribution of Foliose Musci.

Before the time of Dillenius, no attempts seem to have been made to divide mosses into genera. Pharmaceutical writers, indeed, had long been accustomed to name Polytrichum commune, Adiantum aureum majus; and Funaria hygrometrica, Adiantum aureum minus. But these were mere individual appellations for two solitary plants used in medicine; and muscus, with some phrase descriptive of the particular species, or some reference to a previous author, was used as a generic name in common to the whole family. Dillenius saw the inconvenience of this, and remedied it by the institution of genera. But taking the term Musci in an extended sense, he admitted into his admirable *Historia Muscorum* many plants having extremely little affinity to those described in this article. "By the name of moss," says Dillenius, "I designate a class of inferior plants, of which the genera, being more imperfect, consist either of parts that are simple and uniform, being destitute equally of flower and fruit; or they are endowed with diversity of parts, and bear something instead of flowers and fruit, which answers to them." With this latitude of definition, he was enabled to include in his *Historia* some of the minute fungi; a great many Algæ, such as the whole tribe of Confervæ; many Ulvæ, and some Tremellæ, comprehending both under the generic name Tremella; the whole tribe of lichens, under the generic names Usnea, Coralloides, and Lichenoides; besides Lycopodium, (assigned to the Filices of some later authors,) divided into the three Dillenian genera, Lycopodium, Selaginoides, and Lycopodioides. His other genera belong either to the foliose or the hepatic musci. The following six Dillenian genera contain all the foliose musci, which he has described and figured.

- Fructification visible in powdery heads
  - Of two different forms . . . Mnium.
  - Of one form
    - Furnished with an operculum that separates transversely
      - Capsules naked, *i. e.* destitute of a calyptra, generally sessile . . . Sphagnum.
      - Capsules covered with a calyptra,
        - Inclosed in a sheath or calyx, and sessile Fontinalis.
        - Destitute of a calyx, usually situated upon a pretty long fruitstalk,
          - Arising from the axils of the leaves along the branches, and furnished at the base with a scaly involucrum, the leaves of which are different from the leaves of the plant . Hypnum.
          - Arising from the summits of the stems or branches, or from shoots arising from the summits of the stems of the preceding year; not furnished with a scaly involucrum, but arising from a tubercle; the calyptra
            - Smooth . , . . . Bryum.
            - Hairy . . . . . Polytrichum.

The two different sorts of powdery heads ascribed by Dillenius to Mnium, and on account of which he has placed it in a division by itself, are the male and female fructification. The calyptra of Sphagnum, at least that part of it raised by the capsule, is very fugacious, and had escaped the notice of Dillenius; hence he erroneously characterises the genus by the want of a calyptra. The capsules of Fontinalis are now well known not to be sessile, though the fruitstalk is short; and the scaly involucrum, at the base of the fruitstalks of Hypnum, is exactly analogous to the "sheath or calyx" of Fontinalis.

This, as the first attempt at systematic arrangement of musci, is far from destitute of merit; but it is the admirable descriptions and figures of the *Historia Muscorum* which constitute its chief value.

Porella, or, as it is called in *The Conspectus*, Poronia, is placed in this system between Lycopodium and Selaginoides; hence it would appear that it was considered by Dillenius as having more affinity to the Lycopodineæ than to the musci proper. And certainly, abstracting from the difference of texture, there is a very considerable resemblance in habit between some of the bifarious leaved Lycopodia, and of the bifarious leaved Jungermanniæ.

Several plants are introduced which are not referred to any genus. Among these is Buxbaumia aphylla, which has no other name than the descriptive one originally given to it by Buxbaum himself, "Muscus exiguus aphyllos, capitulo crasso and bivalvi." Diphyscum foliosum is reckoned a Sphagnum.

Linnæus' System of Foliose Musci, (from the 13th edit. of the *Syst. Nat.—Vindob.* 1767—70.)

1. Lycopodium, anthera bivalve, sessile; no calyptra.
2. Porella, anthera mutilocular, penetrated by many pores; without operculum and calyptra.

3. Sphagnum, anthera operculate; the mouth smooth; no calyptra.
4. Phascum, anthera operculate; mouth ciliated; calyptra minute.
5. Fontinalis, anthera operculate; calyptra sessile, enclosed in a perichætium.
6. Buxbaumia, anthera operculate, membranaceous on the one side; calyptra caducous; a little bag of pullen within the operculum.
7. Splachnum, anthera seated on a large deeply coloured apophysis; calyptra caducous; stellated female flowers on different individuals.
8. Polytrichum, anthera operculate, seated on a very small apophysis; calyptra villose; female stellated flowers on different individuals.
9. Mnium, anthera operculate; calyptra smooth; female flower, a naked, pulverulent, remote capitulum.
10. Bryum, anthera operculate; calyptra smooth, filament (fruit-stalk) arising from a terminal bulb.
11. Hypnum, anthera operculate; calyptra smooth, filament lateral, arising from a perichætium.

Of this arrangement the first genus, Lycopodium, is now excluded from among mosses. Schreber, considering it to have some analogy in the opening of the capsules to Osmunda, placed it among ferns; and it is now generally considered as the type of a new cryptogamic order; Stachyopterides of Willdenow; Lycopodineæ of others,—a more circumscribed, and better constituted order. The original Porella was transmitted from America by the venerable practical botanist, John Bartram of Pennsylvania, to Dillenius. Linnæus never saw the plant, but characterised the genus from Dillenius's figure and descriptions. It remained a puzzle for several years. Hedwig early considered the genus as altogether doubtful. (See *Fund. Hist. Nat. Musc. Frond.* vol. ii. p. 68, printed in 1782.) And in the 2d edit. of his *Theoria Generationis et Fructificationis Plantarum Cryptogamicarum Linnæi*, published in 1798, he states, in a note, that "specimens of this plant, (Porella pinnata,) which he had lately received from the Rev. Mr. Muhlenberg, though destitute of fruit, show evidently that it belongs to the family of the Jungermanniæ;" and Mr. Dickson having received in the package of a parcel of plants from America, specimens of a plant nearly in the condition of that figured by Dillenius; having ascertained it to belong to the same species by comparison with Dillenius's original specimen; and finding it to be a new species of Jungermannia, described and figured it in vol. iii. of the *Linnæan Transactions*, published in 1797, under the name of Jungermannia porella. The calyx, or the calyptra of the plant, had been taken for the fruit; and the pores were the work of insects. The different compartments in the supposed capsule were a mere mistake of Linnæus, not being mentioned by Dillenius.

It is remarkable, that Linnæus uniformly terms the capsule an anthera, and, of course, the male flowers female. This mistake also was that of Dillenius, who, in his work, very inconsistently called that capsule which he believed to be the anther. Linnæus' notions were originally right on this subject; but yielding to what he considered to be the better judgment of Dillenius in regard to mosses, and reforming his language,—the whole glare of the mistake fell upon himself.

It is unnecessary to make farther remarks on this arrangement. Bating the mistakes in the generic characters, as, for instance, the denial (after Dillenius) of a calyptra to Sphagnum; his own mistake in ascribing a toothed fringe to Phascum; his very singular and altogether false character of Buxbaumia,—it might be not very inconvenient, while only a very few mosses were known. It may appear at first remarkable, that Linnæus has detected none of Dillenius' mistakes, but has copied them all; but when we recollect that Linnæus boasts, in some of the Prefaces to the *Genera Plantarum*, that he scarcely ever used even a pocket glass, we shall cease to wonder at this circumstance. As the work of Dillenius contained, as we have seen, a great many plants that are by no means mosses, the arrangement of Linnæus may be regarded as the commencement of Systematic Muscology—a very rude one, certainly, as most first attempts are; and one, the conception or execution of which, after the work of Dillenius, could involve scarce any difficulty; yet there can be no question that it was useful in the infancy of the science, by calling the attention of botanists to the character and distribution of this family.

Hedwig's System of Foliose Musci.

For the sake of brevity, the essential generic characters given in his Synoptic Table, (at p. 83, 84. of vol. ii. of the *Fundamentum Historiæ Naturalis Muscorum Frondosorum*) only are exhibited.

Capsule	
I. Without any peristome.	1. Phascum.
II. Peristome naked, male flower.	
1 Clubshaped.	2. Sphagnum.
2. Gemmiform.	3. Hedwigia.
3. Disciform.	4. Gymnostomum.
III. Peristome figured.	
A. Single.	
a. Toothed; teeth	
α. Entire	
1. Four in number; male flower varying in form	5. Tetraphis.
2. Eight, apophysis inflated; male flower disciform	6. Splachnum.
3. Sixteen, narrow, erect; male-flower gemmiform	7. Leersia.
4. Sixteen, rather broad, reflexed; male-flower gemmiform	8. Grimmia.
5. Sixteen, rather broad, reflexed; male flowers capituliform	9. Weissia.
6. Thirty-two, connected at the summit by a horizontal membrane	10. Polytrichum.
β. Bifid	
1. Rather long, erect; male flowers gemmiform	11. Trichostomum.
2. Short, inflexed; male flower	
* Gemmiform	12. Fissidens.
** Capituliform	13. Dicranum.
b. Ciliated and twisted; male flower	
1. Gemmiform	14. Tortula.
2. Capituliform	15. Barbula.
B. Peristome double	
a. Dentato-ciliate; teeth	
α. Free at the apex; the cilia	
1. Not cohering at the base	16. Neckera.
2. Cohering by a membranaceous base	
a Uniform	
Male flower gemmiform	17. Leskea.
b Varying in form; the male flower	
* Gemmiform	18. Hypnum.
** Capituliform	19. Bryum.
*** Disciform	20. Mnium.
β. Teeth cohering at the summit	
Male flower disciform	21. Koelreutera.
b. Perist. dentato membranaceous; the teeth	
1. Acuminated; the flowers united	22. Webera.
2. Truncated; the male flower disciform.	23. Buxbaumia.
c. Dentato reticulate; male flower	
1. Gemmiform.	24. Fontinalis.
2. Disciform and united	25. Meesia.

Such is the first modification of Hedwig's system. Its great merit consists in its placing the peristome full in the view of the botanical world, and making it the chief basis of generic distinction. The publication of this system commenced a new era in systematic muscology,—an era since which more progress has been made in the study than in all former ages. The former systems were not indeed at once relinquished for it. For more than twelve years after its first publication, we find some of the most judicious botanists complaining of it, and setting it aside, as too artificial. But every day contributed to make the defects of the Linnæan arrangement more and more apparent, while every day contributed also to remove some of the prejudices which impeded the reception of Hedwig's system. In point of fact, the different arrangements which have been formed, and more or less widely received in Europe during the last thirty years, are, with extremely few exceptions, to be considered as modifications of Hedwig's system, or as formed according to his principles. Those arrangements which form exceptions, have been little noticed, and still less followed. That, for instance, of the late ingenious Baron Palissot de Beauvois, has been very seldom noticed, except with the view of censure; and, as far as we know, has had only one follower, in Mons. Desmazieres of Lille. If our limits had permitted, we would have given a sketch of it as a curiosity.

In a few topical floræ, the arrangement of Linnæus is still retained; but in these works the species, far too numerous for the system, are in such confusion, that we consider these works as nearly quite useless in regard to Muscology.

The system of Hedwig was afterwards very considerably modified by himself. Hedwigia was given up for Anictangium; and the distinction between Gymnostomum and Anictangium was made to consist in Gymnostomum having the male flowers in a terminal head; Anictangium having them axillary. The name Leersia, which other botanists had begun to give to different genera, was exchanged for Encalypta; Koelreutera, for the same reason, became Funaria; and in the species Muscorum, a posthumous work, published in 1801, ten new genera were added. After Tetraphis was inserted, 1. Andræa, defined teeth four, connected at the summit, (it should have been "Capsule quadrivalve," as Ehrhart had discovered long before. See Hooker, in Linn. Trans. v. x. p. 382—387.)

Between Andræa and Splachnum is inserted, 2. Octoblepharum, easily distinguished from Splachnum by the want of an Apophysis. After Encalypta (Leersia) of which the definition is altered to male flower axillary, female terminal on the same plant, three new genera, 3. Pterigynandrum, 4. Cynontodium, and 5. Didymodon have place. Pterigynandrum, in addition to the character of Encalypta, has also male and female flowers axillary on different plants. Cynontodium has both male and female flower terminal, and Didymodon, both male and female flower axillary. These exhaust the new genera with a single fringe.

In the division with a double fringe, we find first of the new genera, 6. Bartramia (immediately following Buxbaumia.) and characterised by the inner fringe being membranous, furrowed, contracted into a cone, finely lacinated at the orifice: Flowers united. After Neckera (the arrangement of the genera being somewhat different in this scheme from the original one,) 7. Orthotrichum, 8. Timmia, 9. Pohlia.—Orthotrichum is characterised by the inner fringe being of ciliary teeth, unconnected; those of the outer approaching each other in pairs. The remaining new genera belong to the subdivision in which the cilia forming the inner fringe arise from a membranous base. Timmia has the teeth uniform, the male flower axillary, the female terminal. Pohlia has the teeth uniform, the flower united and terminal. After Bryum is introduced, 10. Arrhenopterum, and these two genera are distinguished by Bryum having the male flower terminal, in a round head, and Arrhenopterum, as the name imports, the male flower axillary.

We agree with British botanists in general, in considering it rather as a defect in this system, that so much stress should be laid upon the male flowers—parts of much importance certainly in the economy of vegetation; but we think not well suited, in this family, for generic discrimination, while the fruit alone is amply sufficient. On the Continent in general, the male flowers are still resorted to for this purpose; but they are altogether omitted in the British systems. It was quite natural for Hedwig to attach much importance to the male flowers in his system, as he was the first to place beyond a doubt their nature and universality. But a British system of quite recent origin, which we shall presently exhibit, we consider much more convenient, and much more likely to last, than any into which the male flowers are admitted.

Bridel's System of Frondose Musci.

For the sake of brevity, we shall exhibit merely his essential generic characters of Musci, as given in the Analytic Table, with which the Mantissa commences.

I. Plants furnished with a Calyptra and Operculum, the fruit entire—or Musci Frondosi.

SECT. I.

Fruitstalk without any sheath—Evaginulati. 1. Sphagnum.

SECT. II.

Seta inserted into a sheath—Vaginulati.

CLASS I.

Capsules falling off without opening.
Mouth none—Astomi.

ORDER I.

Fruit terminal—Acrocarpi . 2. Phascum.

ORDER II.

Fruit lateral—Pleurocarpi. . . 3. Pleuridium

CLASS II.

Capsules with the mouth naked—Gymnostomi.

ORDER I. ACRROCARPI.

Calyptra. { hoodshaped, lipped, 4. Gymnostomum.
pyramidal, bursting at the side, persistent. . . . 5. Pyramidula.
mitriform . . . . 6. Schistidium.

ORDER II. PLEUROCARPI.

7. Anœctangium.

CLASS III.

Mouth of the capsules surrounded with a peristome. Peristomi.

ORDER I. ACROCARPI.

(*a*) Peristome Simple.
* undivided.
8. Leptostomum.
* * divided.

1mo, *Teeth solitary, entire, free at the base.*

Perist.
- 4-toothed. — 9. Tetraphis.
- 8-toothed. — 10. Octoblepharum.
- 16-toothed Teeth
  - united at the summit. — 11. Conostomum.
  - Free at the summit. Calyptra.
    - between cylindrical and bell-shaped. — 12. Encalypta.
    - mitriform smooth. — 13. Grimmia.
    - sulcated. — 14. Glyphomitrium
    - hoodshaped. Teeth of the Peristome.
      - solid. — 15. Weissia.
      - Perforated Capsule.
        - without an apophysis. — 16. Coscinodon.
        - with an apophysis. — 17. Tromatodon.

2do, *Teeth solitary, split, free at the base.*

Teeth 16, split to the middle. Calyptra.
- hoodshaped — 18. Dicranum.
  - 1 Capsule with an apolysis. *Oncophorus.*
  - 2 Capsule without an apophysis. *Dicranum.*
  - 3 Capsule truncated at the base on the anterior side. *Aegiceras.*
- mitriform — 19. Campylopus.

Teeth divided to the base into sets of 2, 3, or 4. Calyptra.
- mitriform — 20. Racomitrium.
- hoodshaped — 21. Trichostomum.

3tio, *Teeth solitary, split, united at the base by a membrane.* — 22. Desmatodon.

4to, *Teeth solitary, twisted at the summit.*

Teeth
- nearly free at the base, membrane none, or very short — 23. Barbula.
- connected at the base by a broad tesselated membrane — 24. Syntrichia.

5to, *Teeth approximated in pairs.*

Teeth 16 — 25 Cynodon.

32, Capsule
- without an apophysis — 26. Didymodon.
- with an apophysis — 27. Hookeria.

6to, *Teeth in pairs, coalescing.*

Capsule with an apophysis — 28. Splachnum.

(*b*) Peristome simple and compound.

External teeth of the Peristome approximated in pairs and agglutinated. Capsule without an apophysis. Calyptra.
- Plaited and keeled — 29. Orthotrichum.
- Smooth and straited — 30. Ulota.

(*c*) Peristome compound.

1mo, *Teeth of the external peristome free at the summit.*

Ext. per. 16 teeth, rolled outwards spirally.
Internal. A conical membrane, at last split longitudinally into several irregular segments. — 31. Schlotheimia.

Ext. per. 16 lanceolate, acute teeth.
Internal. A very short membrane, divided into 16 teeth, with intermediate prominent dots. — 32. Paludella.

Ext. per. 16 acute teeth.
Internal. An elongated membrane divided into 16 teeth. — 33. Pohlia.

Ext. per. teeth 16, wedge-shaped
Internal. A plicato-carinate membrane, divided into 16 bifid segments. — 34. Bartramia

Ext. per. Teeth 16, rather broad, acute.
Internal. A carinato-sulcate membrane produced into 16 rather broad processes, with cilia interposed.
- Capsule equal. — 35. Bryum.
- unequal. — 36. Arrhenopterum

Ext. per. Teeth 16, rather broad, ascending erect.
Internal. A membrane produced into 16 perforated bifurcated segments (with ciliae interposed ?) — 37. Mnium.

Ext. per. Teeth 16, rather broad, acuminated.
Internal. A membrane divided into 16 segments, the segments variously divided, and anastomosing. — 38. Timmia.

Ext. per. Teeth 16, obtuse, short.
Internal. 16 cilia.
- approximated in pairs, free at the base. — 39. Diplocomium.
- connected by a network. — 40. Meesia.

Ext. per. Teeth 16, acute, inflexed.
Internal. A cupuliform membrane, closed at the summit, 16 times perforated. — 41. Cinclidium.

Ext. per. Scarce any.
Internal. A conical truncated membrane, plaited 16 times, open at the summit. — 42. Diphyscium.

Ext. per. Scarce any; or 16 teeth, by no means truncated; capsule unequal.
Internal.-A conical truncated membrane, plaited 16 times, open at the summit; between the two peristomes a process having the appearance of a torn network, formed like a chaplet. — 43. Buxbaumia.

2do, *Teeth of the external peristome united at the summit.*

44. Funaria.

ORDER II. PLEUROCARPI.

(*a*) Peristome single.

1mo, *Teeth entire, approximated in pairs.*

45. Fabronia

2do, *Teeth entire, equidistant from each other.*

Teeth 16, Calyptra { hood-shaped, smooth, 46. Pterigynandrum.
conical, at the base multifid, smooth, 47. Maoromitrium.
hairy. 48. Lasia.

3tio, *Teeth bifid.*

49. Leucodon.

(*b*) Peristome compound.

5to, *Teeth of the internal peristome free at the base.*

Ext. per. Teeth 16, erecto-inflected.
Int. Cilia 16, opposite the teeth. 50. Antitrichia.
Ext. per. Teeth 16, at last reflexed.
Cilia 16, alternating with the teeth. 51. Anacamptodon.

Ext. per. Teeth 16 erect.
Int. Cilia 16, alternating with the teeth.
Calyptra. {
hoodshaped, smooth. 52. Neckera.
1. capsule subsessile. *Disticha.*
pedunculate. *Neckera.*
mitriform, smooth. 53. Cryphæa.
rough. 54. Pilotrichum,
1. calyptra rough, with hairs. *Pilotrichum.*
2. with chaffy substances. *Lepidopilum.*

2. *The teeth of the internal peristome connected at the base by a membrane.*

Ext. per. Teeth 16, acute.
Int. Cilia 16, connected by transverse bars, arising from a very narrow membrane, divided into two limbs, but united at the summit. 55. Climacium.

Ext. per. Teeth 16, subulate.
Int. A membrane produced into 16 linear uniform processes.
Calyptra. }
hoodshaped. 56. Leskia.
mitriform, rough with hairs. 57. Chætophora.
smooth. 58. Pterigophyllum.

Ext. per. Teeth 16, lanceolate, reflexile.
Int. A membrane produced into 16 processes, with cilia interposed.
Calyptra. }
bell-shaped, slightly lacinated at the base 59. Racopilum.
hoodshaped 60. Hypnum.
1. capsule equal, *Isocarpia.*
2. unequal cernuous, *Hypnum.*

3tio, *Internal peristome without teeth.*

Ext. per. Teeth 16, acute, nearly erect.
Int. A reticulated conical membrane. 61. Fontinalis.

Order III.

Fruit from the duplicature of a leaf. Entophyllo-carpi.

Teeth solitary, bifid. { 8 62. Octodiceras.
16 65. Fissidens.

Class IV.

Mouth of the capsule closed with a horizontal membrane. Epistomi.

Order I.

Mouth of the capsule naked. Gymnostomi.

64. Calymperes.

Order II.

Mouth of the capsule toothed. Peristomi.

Calyptra { clothed - - 65. Polytrichum.
naked - - - 66. Catharinea.

Class V.

Cilia arising below the mouth from the walls of the capsule, and from the columella. Hypostomi

67. Dawsonia.

Appendix.

Plants furnished with a calyptra and operculum, the capsule dividing into valves.

68. Andræa.

This very ingenious system, we cannot help thinking unnecessarily encumbered with hard Greek names of subdivisions. As many of these sections contain each only a single genus, to commit to memory the name of the sections, is, in these instances, just equivalent to learning an additional name for so many genera. We think there is sometimes an inconvenient vagueness of expression in his characters; for instance, when he calls the peduncle of Sphagnum a fruitstalk, though its true nature had been shown in a plate, by Hedwig, 37 years before the Mantissa was published. Besides, several of the genera seem liable to reduction. Thus, Pleuridium, which is separated from Phascum by its lateral fruit, contains one European species, Phascum alternifolium of other writers; in which, indeed, the mature fruit is lateral from innovation; but the flowers and the young fruit are undoubtedly terminal. The only other species is a plant from the Isle of France, which has much the habit of Ph. alternifolium. Bridel has marked it with the sign of doubt. If a good species, we are strongly inclined to anticipate that it will turn out a genuine Phascum. Pyramidula contains only one species, Pyr. tetragona, which, notwithstanding the peculiarity in the Calyptra mentioned in the definition, is considered by Voit as identical with Gymnostomum pyriforme. Schistidium of Bridel is Anictangium of Hooker; and Anoectangium of Bridel is Hooker's Hedwigia. Glyphomitrium, which contains three species, should probably be either blended with the Grimmiae, or divided between Encalypta and Grimmia. Coscinodon, a genus defined by Sprengel to contain certain mosses with perforated teeth, cannot be tenable, unless the definition be amended; as we find species with perforated teeth in Grimmia, Weissia, Trichostomum, and Didymodon, and having the closest affinity, in habit and systematic relation, with the other species of this genera. Indeed, the genus seems to be composed entirely of species of Weissia and of Didymodon. Campylopus of Bridel has been formed to receive certain Dicrana, at least one Trichostomum, and some Grimmiae, with an utter disregard of the Calyptra, though it is defined to be "mitriform at the base lacero-fimbriate." Racomitrium contains, of well known species, chiefly those Trichostoma with the teeth divided. Desmatodon contains two Dicrana, and Barbula curta of Hedwig. But it would be tedious to go through the whole system in this manner. Under his 68 genera, Bridel has assembled 961 species, by far the greatest number hitherto published in any one work. Of these species, indeed, a considerable number will be found, on examination, to be mere varieties. Yet, even after deducting for these varieties so large a number as 160, or even 200, we have in that work a collection of species far greater than is elsewhere to be found in a single work. The want of figures, and its occasional mistakes, and vagueness in definition, are its chief defects as a collection of species.

Bridel's references are very curious, in general accurate, and valuable. Yet at some of them it is impossible to avoid smiling. He is very fond of referring to Adanson's *Familles des Plantes*, and not unfrequently refers to the same Adansonian name, plants of the most heterogeneous appearance, and belonging to genera that assort extremely ill together. Thus, to

Luida are referred one species of Splachnum; several Trichostoma, Fissidentes, Dicrana, Tortulae, Barbulae, Neckerae, Hypna, Brya; two species of Mnium, two of Bartramia, the Genus Octoblepharum, and some Weissiae. To *Bryon* are referred some Gymnostoma, some Leersiae, (Encalyptae,) several Splachna, one Trichostomum, one Tortula; several Barbulae; one Arthenopterum, two Mnia, one Funaria, two Weberae, and one Meesia. To *Green* are referred the genus Phascum; some Sphagna, and some Grimmiae. To *Harisona* are referred some Hedwigiae (Anictangia and Gymnostoma), some Fissidentes, several Neckerae and Fontinalis Squamosa! It is unnecessary to multiply examples, and indeed these are the most remarkable. The amount of the incongruity does not consist merely in the assemblage of heterogeneous species under the same genus, but in the breaking down of natural genera, that their species might be divided, and parcels of them blended under one Adansonian name, with parcels of species belonging to other genera, having no imaginable affinity with them. Thus, while all the other Splachna, known to Adanson, seem, according to Bridel, to belong to the genus *Bryon*, what is there in Splachnum ampullaceum, to make it, with so many plants totally unlike it, a Luida? By what possible art can species of Gymnostomum, Fissidens, Neckera, and Fontinalis squamosa, be comprehended under one generic definition? And this allotment of F. squamosa is the more singular, as all the other species of Fontinalis belong to Adanson's genus of the same name. Luida, as represented by Bridel, is merely a mass of confusion.

It is quite evident, that it would be in vain to search for the reason of these very whimsical arrangements in the meagre definitions given in the *Familles des Plantes*; and that, if the citations be worth any thing, they must have been obtained either from a Herbarium, or from a pupil of Adanson, thoroughly imbued with the notions of his master. We wish that Bridel had in this instance referred to his real authority, instead of referring to a book which gives us no assistance in unravelling these intricacies. But, whatever the real authority was, we would hope, for the honour of the French naturalist, that it had been very often mistaken.

Dr. Hooker's System of Foliose or Operculate Mosses.

Division I. Mouth of the Capsule destitute of Teeth.

* *Capsule Valvular.*

Genus 1. Andraea. Capsule quadrivalve; the valves held in proximity at the apex by means of the persistent lid; calyptra irregularly torn.

Of this genus, first defined by Ehrhart, and adopted by Hedwig and by all subsequent muscologists, four species are known, all of which are indigenous to Britain. They are inhabitants of alpine rocks; of a very dark colour, and rigid texture. Linnæus, who was acquainted with two of the species, having overlooked the columella and persistent lid, described them as Jungermanniae. They would have been published under the name now universally received, in the Methodus Muscorum of the younger Linnæus, had he not, with misplaced indignation, cancelled Ehrhart's original sheet, containing the alteration, and restored his father's arrangement. The nearest affinity of this genus, among Foliose Mosses, is to Sphagnum, on account of its sessile capsule. The species most prized is A. nivalis, (Musc. Brit. t. 8.) one of the two with nerveless leaves, a moss peculiar to Britain, which is characterised by the stems being slightly branched, leaves loosely imbricated, subfalcate, subsecund; those of the perichaetium similar to those of the stem.

** *Capsule entire.*

a. Capsule sessile, receptacle pedunculate.

II. Sphagnum. Receptacle pedunculate, peduncle resembling a fruitstalk. Capsule sessile, entire, its lid deciduous, its mouth naked; calyptra irregularly torn.

Contains four species, all of which were comprehended, by Linnæus, under his Sph. palustre, and are common in marshy situations and bogs. By colour alone they may be easily discriminated from all other British mosses, except Dicranum glaucum.

b. Capsule on a fruitstalk, receptacle sessile.

III. Phascum. Fruitstalk terminal. Operculum adnate. Calyptra dimidiate, (short, fugacious.)

Contains 17 British species, according to Sir J. E. Smith, (*Comp. Fl. Br.* 2d and 3d edit.) which are reduced in the Musc. Brit. to 11 species.

The Phasca are among the minutest mosses known, and Ph. serratum, the smallest species, is, besides, remarkable for its creeping, articulated, branched, leafless conferva-like shoots, which appear to be merely the primary expansions of the seed in germination, persistent in this instance, as the primary lichenoid expansion of Acrostichum alcicorne is among ferns. In most of the Phasca the fruitstalk is very short, and the fruit immersed among the perichaetial leaves.

IV. Voitia. Fruitstalk terminal. Operculum adnate. Capsule deciduous with the fruitstalk. (Calyptra large, persistent.)

This genus was first defined by Professor Hornschuch, on account of a moss, (V. Nivalis, Musc. Exot. t. 97. the only species at present known,) which he found by the snow line on the Carinthian mountains. The genus is distinguished from Phascum by the large persistent calyptra, and the deciduous fruitstalk, which, in the only species known, is about an inch in length; and the whole habit is very unlike that of any known Phascum.

V. Gymnostomum. Fruitstalk terminal. Mouth of the capsule naked. Calyptra dimidiate.

Contains fourteen British species, according to the Musc. Brit. and nine foreign mosses, considered as species of this genus, are figured in the Musc. Exot. Among these foreign species are the mosses which had been comprehended in the new genus Leptostomum, by the distinguished Mr. Brown; a tribe of plants marked by a very peculiar habit; a gibbous capsule, approaching, in some instances, to the form of that of Diphyscium; and an annular membrane arising within the walls of the capsule, traversing its mouth. As a horizontal membrane, with a similar origin, has been found to cover the mouth of the capsule of four British species, (most easily perceived in G. griffithianum) the Leptostoma have been provisionally included by Dr. Hooker within his definition of Gymnostomum. In that genus plants of such singularly different habits are now included, that it seems not unlikely that the discovery of a few new species additional may induce muscologists, not merely to replace Leptostomum, (perhaps with some alteration in the character,) but to form generic definitions for other parcels of Gymnostomum as at present constituted. Glyphocarpa of Brown, in particular, we wish much to see separated.

VI. Drepanophyllum. This genus has been proposed by Professor Richard for the reception of a very singular moss, Drep. fulvum which he found growing on trees in the woods of French Guyana. The species is dioecious, the male and female plants differing much in aspect. Mouth of the capsule naked. A thin upright membrane arises from the inner side of the mouth of the capsule. The operculum is depressed at the summit. The stem erect, flexuous, branched. The leaves bifarious, scymetar-shaped, arising alternately from the anterior and posterior sides of the stem; the nerve running along the lower margin. Colour of the leaves lemon-yellow.

Notwithstanding the singularity of the habit of this moss, there seems to be no technical character at present known to separate it from Gymnostomum. Before seeing the mouth of the capsule (*Musc. Exot.* t. 125.) it was supposed by both Schwaegrichen and Hooker to belong to the bifariously-leaved Dicrana.

VII. Anictangium. Fruitstalk terminal. Mouth of the capsule naked. Calyptra mitriform.

Contains two British species, of which Anict. ciliatum is a very common moss, of a hoary aspect, with the capsule immersed; occurring upon rocks and stones, at a lower elevation than the hoary Trichostoma, with diaphanous points to the leaves; and Anict. imberbe is peculiar to Ireland. France possesses another species, Anict. lapponicum. Germany, Anict. aquaticum; other two species, natives of New Holland and South America, are figured in the Musci Exot. and we have received specimens from North America of two species different from any of these.

VIII. Schistostega. Fruitstalk terminal. Mouth of the capsule naked. Lid laciniated. Laciniae deciduous.

This genus, first defined by Hedwig, contains only one known moss, Schist pennata, which has been only once found in Britain, in a particular spot in Devonshire, by Mr. Newberry. It is Gymnostomum osmundaceum of *E. B.* v. xxxi. t. 2213. a minute plant, having much resemblance in habit to Dicranum bryoides.

Regarding this genus we transcribe a note from Bridel: "Schkur, a most acute investigator of mosses, intent only on truth, has shown that Hedwig erred greatly in the observation, description, and representation of the operculum of this moss. For Hedwig described and figured those delicate Striae, radiating from the centre to the circumference, with which the operculum is adorned, as fissures, by which the operculum splits into a great many parts, (a circumstance which might possibly occur in a solitary instance.) instead of falling off entire, as in other mosses. Weber and Mohr, induced by so great an authority, and even affirming that they themselves had observed the same circumstance, formed for it the new genus Schistostega, so named from the split operculum. But Schkur, having long and pertinaciously scrutinized the capsule of this moss, found that it is in no other manner reticulated, nor does it separate in any other manner than in other mosses, though he confesses that it is very tender and fugacious. Therefore nature herself sets aside the genus Schistostega; and that name will remain in muscology only like Trentepohlia—a proof that the best observers may easily fall into error, if they examine nature carelessly, or with a prejudiced mind."

Without going quite so far as Bridel in regard to this genus—since the authorities at present in its favour are Hedwig, Weber, and Mohr, "all most acute investigators, intent only on truth," while against it is quoted only Schkur, yet we own that we should not be much surprised were the genus to be reduced, and the only species of it to be known hereafter by the name of Gymnostomum pennatum.

IX. Hedwigia. Fruitstalk lateral. Mouth of the capsule naked. Calyptra dimidiate.

As thus defined, the genus is altogether exotic. In *Musc. Exot.* four species are figured, of which one is indigenous to the Carinthian Alps; one to Teneriffe; and two to tropical America.

X. Lyellia. Capsule plane on the one side, convex on the other. Its mouth closed with a (thick, depressed) membrane, of which the circular disc, separating from the (broad) persistent limb, remains attached to the permanent included Columella. Calyptra hood-shaped, (or dimidiate,) hairy on the summit.

This genus, defined by Mr. Brown, contains only one species, Ly. crispa, gathered by the Hon. Col. Garner, in Nepal. In the membrane covering the mouth of the capsule, it is totally unlike any other known moss; yet in general aspect it has several points in common with Dawsonia, Polytrichum, and Buxbaumia.

XI. Diphyscium. Fruitstalk terminal. Capsule plane on the one side, convex on the other. A plicate membrane, in the form of a truncated cone, arising from the inner side of the mouth of the capsule. Calyptra mitriform.

Contains only one species, D. foliosum, the Buxbaumia foliosa of authors. It is separated from Buxbaumia on account of its wanting the row of teeth exterior to the membranous fringe, which occurs in B. aphylla. D. foliosum is not uncommon in various parts of Britain. It is very plentiful in Peebles-shire.

Division II. MOUTH OF THE CAPSULE FURNISHED WITH TEETH.

* *In a single row.* (*Peristome single.*)

XII. Polytrichum. Peristome simple, of 32 or 64 equidistant incurved teeth, connected at the summit by a horizontal membrane. Calyptra dimidiate.

Contains 10 British species. There are besides two species, P. capillare, and P. laevigatum, peculiar to Lapland; and other four species are figured in the *Musc. Exot.*

In one section of this genus, the Catharinea of authors, the calyptra is always smooth; in the other it is hairy, owing to the adherence of the succulent filaments of the flower, occasioned by a viscid exudation common to them and to the calyptra.

XIII. Tetraphis. Fruitstalks terminal. Peristome single, of four equidistant upright teeth. Calyptra mitriform.

Contains only two species, both of which are indigenous to Britain, and neither rare.

XIV. Octoblepharum. Fruitstalk terminal. Peristome single, of eight double teeth.

Contains two species, both exotic, of which the one, O. albidum, is common to both hemispheres, and widely distributed; the other, O. serratum, has been hitherto found only in Nepal, and in the Isle of Bourbon.

XV. Fabronia. Fruitstalk lateral. Peristome single, of eight double teeth.

Of this genus, which is altogether exotic, and differs from Octoblepharum by the lateral insertion of the fruitstalk, two species are figured in the *Musc. Exot.*

XVI. Splachnum. Fruitstalk terminal. Peristome single, of eight double teeth. Capsule seated on an apophysis. Calyptra mitriform, entire.

Contains eight British species, all of which delight in alpine situations; several of which are rare, and much prized, particularly Spl. frœlichianum, Spl. vasculosum, Spl. angustatum, and Spl. mnioides. Three species, and these among the finest of this genus, are peculiar to Lapland, viz. Spl. rubrum, luteum, and urceolatum. The apophysis of Spl. rubrum is umbrella-shaped, of a brilliant red, and much larger than the capsule. That of Spl. luteum resembles a reversed umbrella, and is still larger in proportion to the capsule, and of a fine yellow. Two additional species, the one from tropical America, the other from (the trunks of dead trees! in) Van Diemen's Land, are figured in the *Musc. Exot.*

XVII. Systylium. Peristome simple, of 16 pairs of short teeth, united at the base. Operculum connate with the columella, persistent. (Capsule furnished with an apophysis.)

A genus defined by Professor Hornschuch, which contains only a single species, Syst. splachnoides. *Musc. Exot.* t. 98, found by the Professor in only one place, on a micaceo-schistose rock, in the Alps of Upper Carinthia.

XVIII. Tayloria. Peristome simple, of 32 very long twisted teeth, approximated in pairs. Capsule furnished with an apophysis.

This genus was first defined by Schwægrichen, under the name Hookeria, which had been pre-occupied by Sir J. E. Smith, in the ninth volume of the *Lin. Trans.* Since Schwægrichen's name could not be retained, Dr. Hooker devoted the genus to Dr. Taylor of Cork, his friend and able coadjutor in the *Muscologia Britannica.* Tayl. splachnoides is an alpine moss, that inhabits Norway, Switzerland, and the North of Germany.

XIX. Tortula. Fruitstalks terminal. Peristome single, of 32 filiform twisted teeth, more or less united at the base into a tubiform membrane. Calyptra dimidiate.

Contains 11 British species, of which T. stellata, found hitherto only by Mr. Dickson, is the most rare, and is peculiar to Britain. T. cuneifolia, common in Devonshire, seems to be rare elsewhere, and perhaps has not hitherto been found in Scotland. Five new species are contained in the *Musc. Exot.*

XX. Cinclidotus. Fruitstalks terminal. Peristome single, of 32 filiform twisted teeth, anastomosing at their base. Calyptra mitriform.

This genus was first defined by De Beauvois, in the Prodrome d'Ætheogamie. It contains only one species, Cinc. fontinaloides, the Fontinalis minor of Linnæus, and Trichostomum fontinaloides of Hedwig and Smith. The calyptra is sometimes split on one side.

XXI. Conostomum. Fruitstalk terminal. Peristome of 16 equidistant teeth, all united at their summits. Calyptra dimidiate.

This genus was established by Swartz in Schrader's Journal. It contains only one British species, C. boreale, the Grimmia conostoma of Sir J. E. Smith. It is an alpine moss. Only another species, C. australe of Swartz, native of North America, at the Streights of Magellan, is known. Both species approach the Bartramiæ with terminal footstalks, very much in habit.

XXII. Encalypta. Fruitstalks terminal. Peristome single, of 16 teeth. Calyptra campanulate, smooth, entirely enclosing the mature capsule.

Contains three British species, of which E. streptocarpa is very rare in fructification; in which state it was found by Dr. Hooker, on the Duke of Atholl's grounds at Dunkeld, in 1815. The other two species are common.

XXIII. Weissia. Fruitstalk terminal. Peristome single, of 16 entire equidistant teeth. Calyptra dimidiate.

Contains 18 British species, of which W. splachnoides, W. Templetoni, W. trichodes, W. calcarea, W. pusilla, are among the most rare. W. Templetoni is peculiar to Ireland. Five new species are figured in the *Musci Exotici.*

XXIV. Pterogonium. Fruitstalk lateral. Peristome single, of 16 entire equidistant teeth. Calyptra dimidiate.

Contains three species, of which P. Smithii, a species which Sir J. E. Smith gathered almost immediately on landing in England from his travels, and which was not before known to be a native moss, and Pt. filiforme, are rather rare British species. Our other species, Pt. gracile, is common. Four new species are figured in the *Musc. Exot.*

XXV. Calymperes. Fruitstalk terminal. Peristome single, of a spongy horizontal membrane, completely covering the mouth, at last divided in the middle into 16 short teeth. Calyptra large, mitriform, involving the capsule, at last divided laterally.

Of this genus, first defined by Swartz, three species are known; of which two, C. lonchophyllum, and C. Palisoti, natives of the West Indies and of Africa, are figured by Schwægrichen; the third, C. Garneri, a native of Nepal, from which it was sent by the Hon. Col. Garner, is figured in the second volume of the *Musc. Exot.* It is a singular genus, and seems to be confined to warm countries.

XXVI. Grimmia. Fruitstalk terminal. Peristome single, consisting of 16 equidistant teeth, entire or perforated, (very rarely split.) Calyptra mitriform.

Of this genus, seven species are indigenous to Britain. Gr. saxicola, Gr. Daviesii, and Gr. Doniana, are rare. Five new species are figured in the *Musc. Exot.*

XXVII. Dicranum. Fruitstalk terminal. Peristome single, of 16 bifid teeth. Calyptra dimidiate.

Contains 24 British species, of which D. latifolium, D. longifolium, D. spurium, are the most rare. D. glaucum is rare in fruit. The *Musc. Exot.* contain seven new species.

XXVIII. Trichostomum. Fruitstalk terminal. Peristome of 16 teeth, divided to the base, or 32 approximated in pairs. Calyptra mitriform.

Contains nine British species, none of which is peculiarly rare. The *Musc. Exot.* contain two additional species.

XXIX. Leucodon. Fruitstalk lateral. Peristome single, of 16 split teeth, or 32 closely united in pairs.

Only one species of this genus, L. sciuroides, is British, and of it the fruit is very rare. L. canariensis is another species figured by Schwægrichen; and five new species are figured in the *Musc. Exot.*

XXX. Didymodon. Fruitstalk terminal. Peristome single, of 16 teeth, cleft to the very base, or nearly so, or 32 approaching in pairs, or united at the base. Calyptra dimidiate.

Contains eight British species, of which the most rare, at least in fruit, D. flexifolium, was found abundantly in that state last summer, by Mr. Greville, in Devonshire, with the teeth in good condition, and the genus of this moss no longer remains uncertain. D. inclinatum, and D. rigidulum, are also rare. The *Musc. Exot.* contain two new species, besides D. splachnifolium, which is the Weissia obtusa of Bridel.

*** In a double row.* (*Peristome Double.*)

XXX. Funaria. Fruitstalk terminal. Peristome double, oblique; the outer of 16 teeth; the inner of 16 teeth, opposite those of the outer.

Three British species belong to it, of which F. hibernica, "found on the roof of a thatched cottage at Blarney, near Cork." by Mr. Drummond, is the rarest.

XXXII. Zygodon. Fruitstalk terminal. Peristome double; the exterior of 16 teeth, approaching in pairs; the interior of as many horizontal cilia. Calyptra dimidiate, short.

Contains only one British species, Z. conoideum, which grows always on trees, and has been found near Inverary, Scotland, by Mr. Dickson; in Mr. Templeton's orchard at Orange-grove, Ireland; and near Manchester, by Mr. Hobson. Another species, Z. obtusifolium, sent from Nepal by the Hon. Colonel Garner, is figured in the *Musc. Exot.*

XXXIII. Orthotrichum —Fruitstalk terminal; Peristome double, exterior of 16 teeth, approaching in pairs; the interior consisting of 8 or of 16 cilia, or wanting. Calyptra mitriform.

Ten British species belong to it, of which the last discovered and rarest is O. Lyellii, found by Mr. Lyell "on trees in the New Forest, Hants." O Hutchinsiæ is the only other rare species, and is exclusively, or chiefly, Irish. Nine new species are figured in the *Musci Exot.*

XXXIV. Sclotheimia. Fruitstalk terminal. Peristome double; exterior of 16 revolute teeth; the interior a conical plaited membrane, irregularly torn.

A tropical genus very nearly related to Orthotrichum. The only species of it figured in the *Musc Exot.* Scl. sulcata, was sent from Nepal by the Hon. Colonel Garner, and "has such a resemblance to Orthotrichum longifolium, that it can be distinguished only by the Peristome." The genus seems to have been first characterized by Schwaergrichen.

XXXV. Neckera. Fruitstalk lateral; the exterior of 16 erect free teeth; the interior of 16 cilia, connected only at the very base by a short membrane; Calyptra dimidiate.

Contains two British species, of which N. pumila is rare in Scotland; nor is the fruit of N. crispa abundant. Eight new species, and three that had been previously figured, have place in the *Musci Exotici.* It is proper to remark, that the character of the genus, as given in the *Musci Exot.* is more extensive than that in the *Muscologia Britannica*, which we have here exhibited; and hence it is not impossible that some of these species may belong to the following genus.

XXXVI. Anomodon. Fruitstalk lateral; peristome double; consisting of 16 teeth, and a ciliary process arising from the side of each tooth; calyptra dimidiate.

Contains two British species. The fruit of A. curtipendulum is rather rare.

XXXVII. Daltonia. Fruitstalk lateral; peristome double, consisting of 16 teeth, and a ciliary process arising from the side of each tooth; calyptra mitriform.

Contains two British species, both of which are rare.

XXXVIII. Fontinalis. Fruitstalk lateral; peristome double; the exterior consisting of 16 teeth, the interior of 16 cilia, connected by transverse bars, and forming a reticulated cone; calyptra mitriform.

Of this genus three species are British; of which F. capillacea is of extreme rarity, and F. squamosa somewhat rare.

XXXIX. Buxbaumia. Capsule oblique, gibbous; peristome double; the exterior of numerous jointed filiform processes; the interior a plaited membranous cone; calyptra mitriform.

This single moss was first discovered in Britain by Dr. Hooker. It has subsequently been found by Mr. E. Maughan, near Roslin; by Mr. Jackson, near Aberdeen; and by the writer of this article, for three successive years, on the mountains of Nubie, Peeblesshire. This last habitat is much more abundant than any of the others, and does not appear likely to be exhausted.

This moss has now for some time been well known to have leaves, see *Edin. Philos. Journal*, vol. ii. p. 377; and the original description of Buxbaum, in which the capsule is said to be bivalve, is occasionally applicable to the plant in a state of decay.

XL. Bartramia. Fruitstalk terminal; peristome double; the exterior of 16 teeth; the interior a plaited membrane, divided into 16 bifid segments; calyptra dimidiate.

Contains six British species, none of which is peculiarly rare. Two new species, and two that had been previously dscribed, are figured in the *Musc. Exot.*

XLI. Bryum. Fruitstalks terminal; peristome double; exterior of 16 teeth; interior a plaited membrane divided into 16 segments, usually alternating with cilia. Calyptra dimidiate.

Contains 25 British species, of which Br. triquetrum, and Br. rostratum, seem to be the most rare. Br. rostratum, in most winter seasons, is abundant in fruit at Braid Hermitage. We have found the exterior teeth of Br. dealbatum, in specimens gathered at Gulane, to be exactly half the length of the cilia, making it a true Meesia. The fruit of Br. roseum is very rare. Three new species are figured in the *Musc. Exot.*

XLII. Hookeria (of Smith.) Fruitstalks lateral; peristome double; exterior of 16 teeth; interior of a membrane divided into 16 entire segments, with sometimes cilia alternating. Calyptra mitriform.

Of this genus, two species are British; and Hook. lætevirens, found hitherto only in a bog near Cork, by Mr. Drummond, is extremely rare. Its leaves are furnished with two nerves running nearly to the summit. Six new species, and two that had been previously published, are figured in the *Musc. Exot.*

XLIII. Leskea. Fruitstalks lateral, peristome double, exterior of 16 teeth; interior of a membrane divided into 16 segments, with no cilia interposed. Calyptra dimidiate.

All the British Leskeæ are thrown into the genus Hypnum in the *Muscologia Britannica*, on account of the difficulty in the discriminative character of these genera; and because, if the species in a topical flora be well arranged, they may be more conveniently discriminated without the separation. "But," says Dr. Hooker, in No. 28 of the *Musc. Exot.* "in a work on foreign mosse, I think it right, at least for the present, to adopt the genus Leskea, though I must again repeat it as my opinion, that it is not founded in nature. The genus Hypnum is now of such vast extent, that, in cases where the peristome can be well examined, it is convenient to have recourse to such characters as are afforded by the Hedwigian families of Leskea and Hypnum."

Under this generic name are described in the *Musc. Exot.* seven new species.

XLIV. Hypnum. Fruitstalks lateral; peristome double; exterior of 16 teeth; interior a membrane divided into 16 segments, with alternate cilia. Calyptra dimidiate.

Of Hypna (including also under that name the genus Leskea,) the British flora contains 60 species. Of these, H. reflexum, H. molle, H. moniliforme, a new species discovered in Ireland by Mr. Mackay, H. catenulatum, H. rufescens, H. flagellare, H. blandovii, H. polymorphum, H. rugulosum, H. silesianum, and H. crista castrensis, are the most rare. The fruit of various other species has been reckoned very rare, as, for instance, of H. dendroides, which has been found in great abundance by various botanists in the neighbourhood of Edinburgh. See Mr. Stewart's *Hortus Cryptogamicus Edinensis*, fasc. 1. The fruit of H. proliferum, H. alopecurum, H. Schreberi, H. squarrosum, the var. revolvens of H. aduncum, all of which are reckoned more or less rare in fruit by Sir J. E. Smith, have also been found most abundant in that state in this neighbourhood, by various botanists. But the fruit of H. fluitans, H. cordifolium, H. stellatum, and H. scorpioides, seems to be rare in the extreme in this neighbourhood, though formerly the late Mr. Don gathered H. cordifolium in fruit at Duddingston Loch.

The number of new Hedwigian Hypna figured in the *Musc. Exot.* is 17; of which one species is doubtful. An additional species, H. flexile, had previously been repeatedly described.

*** *Cilia numerous, arising from the inner side of the walls of the capsule below the mouth, and from the columella!*

XLV. Dawsonia. Capsule convex on the one side, plane on the other; peristome penicillated, cilia very numerous, capillary, straight, equal, arising from the walls of the capsule, and from the columella. Exterior calyptra, a plexus of hairs; interior rough at the summit.

Of this very singular genus, only one species, D. polytrichoides, is known. It was discovered by Mr. Brown at Port Jackson, and the genus was named by him, in vol. x. of *Linn. Trans.* after "that incomparable cryptogamist," Dawson Turner, Esq. of Yarmouth.

The genus is introduced by Dr. Hooker in the system, immediately after Liellia. Natural affinity certainly brings it near to that genus and to Polytrichum; but on account of its innumerable cilia, we prefer, with Bridel, placing it at the end of the system.

Such is the system of Dr. Hooker, a system which we think more likely to last than any other hitherto proposed. The Doctor's pencil has so admirably illustrated every genus—we may add, every species of which he has treated—that no room is left to an attentive reader for mistake, or even doubt. And we are persuaded, that it will not soon undergo any other material alteration, than the introduction of a new genera in the progress of discovery.

ORDER II. MUSCI HEPATICI, OR DEOPERCULATI.

THIS order is easily distinguished from the foliose or operculate musci, by the want of an operculum, and by that part of the calyptra which is separated by the elongation of the fruitstalk, or growth of the capsule, falling immediately. In some instances, the calyptra merely splits, without the separation of any part, to allow the capsule to escape.

The natural character of this order may be stated thus:

Flowers diœcious or monœcious, destitute of succulent jointed threads, usually on a proper receptacle, but in the genus Marchantia, on a common one. In situation they are radical, axillary, or terminal; they very rarely originate from the underside of a frondose stem.

Male flowers.

Calyx, none; except, perhaps, in the genus Anthoceros, in which the cup-shaped receptacles may be termed calyces.

Stamens. Anthers in general spherical or ovate, but varying in form in different genera, and even species; imbedded in a common peltate or wartlike receptacle; in the substance of the frond; sessile, or on short filaments on the upper or lower side of the frond; or on filaments, in general more elongated, and situated, in general, several together within the same leaf, but sometimes solitary; the leaves in the axils of which they occur, are in general closely imbricated, but sometimes patent.

Female flowers.

Calyx rarely absent, monophyllous, containing several pistilla, rarely a single pistillum.

Calyptra bell-shaped; attached to the receptacle; free around the germen; forming the outer covering of the style, and a considerable part of the stigma.

Pistilla various in form; germen ovate; sometimes obovate; rarely spherical; style filiform; stigma in general somewhat widened.

Pericarp, unknown in Sphærocarpus; in the others a capsule, valvular, or at least toothed, except in Riccia; generally situated on a fruitstalk, sometimes sessile or immersed; containing numerous seeds, intermingled, in most instances, with elastic filaments, which are usually spiral.

Seeds, in general spherical or ovate, smooth and brownish; but they vary considerably in form, surface, and colour.

Minute plants, of annual, biennial, or perennial duration, the greater number of the species of the order leafy, and all these species belong to one genus; some other species of the same genus, and all the species of the other genera, are frondose. They grow erect, or less or more inclined, or they creep along the ground. They always prefer moist situations; and, in some few instances, grow in water.

Anatomy and Physiology of Musci Hepatici.

Like the foliose mosses, the Hepatic consist entirely of cellular tissue.

Except in the section of frondose species, in which the texture is comparatively dense, the cellular tissue of the Jungermanniæ is much more lax and delicate than that of the foliose musci. Hence many of the species will wither almost as soon as they are gathered, if they are not immediately put into a vasculum, or laid out in paper.

In this genus, the cellular tissue contains a clear fluid, with particles of different colours in different parts of the same species, and sometimes varying in different varieties of the species, swimming in it. In the stems, when the plants are in health, these particles are usually of an olive-green or purple colour. In the leaves, they vary in colour in different species, being brown in J. juniperina, purple in some varieties of J. nemorosa, J. compressa, &c.

All the species of the other genera are invariably frondose.

The species of Marchantia are of a dense firm texture, somewhat carnose, evidently reticulated, the prevailing colour of the upper surface a bright green, with a light coloured prominent spot in each reticulation; the under surface is covered with a membrane, frequently rugose, in which the green is less vivid, or it sometimes is of a reddish colour. In M. hemisphærica, the under surface is of a dark purple.

In structure, the genus Targionia approaches nearest to Marchantia, of which indeed it has completely the habit; the same dense texture, the bright green upper surface, with numerous light-coloured prominent spots of the frond. The under surface is quite black; in some instances it would appear that it is covered with reddish membranes.

In Riccia glauca, the best known, and indeed the only certain British species of this genus, the form and size of the cells is remarkably regular, being nearly oval, and all nearly of the same size, except towards the edges. It is of a thick carnose consistency, and is roughened with prominent points on the surface, thus evincing some affinity to Marchantia, though it differs remarkably in several other particulars, to be afterwards mentioned.

In Sphærocarpus, the texture is considerably different, being much more delicate and membranous. Its cellular structure is sufficiently obvious under the microscope, and the cells, though often hexagonal, or pentagonal, appear to vary remarkably in form.

In delicate membranous habit, Anthoceros approaches somewhat near to Sphærocarpus; and when sterile, it has considerable resemblance to minute fronds of Jungermannia epiphylla. Its reticulations, as seen under the microscope, are pretty regularly hexagonal; and in Anthoceros lævis have, like Marchantia and Riccia, a prominent spot in the centre.

In Monoclea, the external appearance of the frond is considerably like that of Jungermannia epiphylla; but the texture is much more dense and coriaceous, and the reticulations are indistinct.

CONSERVATIVE ORGANS OF HEPATIC MUSCI.

1. *Roots.*

These, bating accidents, are never wanting in the family of hepatic mosses, unless in the two aquatic species, Riccia natans, and R. fluitans. Both primary and secondary roots occur in the family, the primary roots in general decaying soon, are considered rare, and have been found only in some of the leafy Jungermanniæ, such as J. asplenioides, J. Hookeri, &c.; in the former of which the branched root descends, in the latter it spreads horizontally. The structure of these primary roots does not differ from that of the stem; but they are paler in colour, and more succulent. The species which are furnished with primary roots all grow more or less upright.

Secondary roots abound in the family. In the frondose species, they oft pullulate in great profusion from the whole of the under surface of the frond, or from a great part of it; and particularly from the nerve, where the species is furnished with one. Indeed, with the exception of the two aquatic Ricciae already alluded to, there does not appear to be any species of hepatic moss which is destitute of them; though sometimes they are very minute, and require careful examination before they can be discovered. Specimens of Jungermannia pinguis, found floating on the water, are sometimes altogether destitute of roots of any sort; but this seems to be an accident owing to the unnatural situation. In Sphærocarpus, it would appear that the anomaly occurs of each frond being supported by a single root. When the species is procumbent, or more or less inclined, the roots always originate from the lower side of the stem, whether it be leafy or frondose. In the species of Jungermannia furnished with stipules, they grow in bundles immediately under the stipules; in the exstipulated species, from any place indifferently, on the lower side of the stem. In J. tribolata, J. setacea, &c. they grow even from the branches proper to the fructification. The calyx itself of J. trichomanis sends forth a few fibrous radicles from its upper part; but these must be carefully discriminated from the hairs which surround the calyx of that moss, which always point upwards, while the roots descend. Sometimes a singular inflation appears at the lower end of the roots of J. anomala, which seems to be an effect of disease. As in the foliose mosses, roots also proceed sometimes from the leaves, as in J. complanata.

In structure, the secondary roots of this order of plants appear to be tubular throughout; as under the microscope they exhibit no appearance of division by constriction or articulation. In general they have a considerable degree of transparency, and are of a cloudy whitish colour, sometimes nearly colourless. A brownish tint is occasionally observed in the roots of some Jungermanniæ; which is supposed to be derived from the soil in which they grow. In J. pusilla, and Marchantia hemisphærica, they are of a deep purple colour; a shade of which may also be sometimes perceived in the roots of J. hyalina, J. excisa, and J. ventricosa. In Targionia hypophylla, they are black. In Marchantia polymorpha, they are usually of a shining brown, though sometimes whitish.

2. *Stems and Branches.*

In the leafy species of Jungermanniæ, the stem is either cylindrical, or it tapers to a point. In the frondose hepatic mosses, it is usually more or less flattened. In the genera Anthoceros, Sphærocarpus, Riccia, and Monoclea; and in Jungermannia multifida, and J. pinguis, in which no nerve can be traced, the whole frond seems to be of the nature of a stem, and to be destitute of any leafy expansion. In these instances then, the flattening of the stem attains its utmost extent, having in Anthoceros and Sphærocarpus, a thin, delicate, membranous appearance.

In both the leafy and frondose species of this order, the stem is in some instances simple, in others branched. It is simple, among the leafy species, in J. scalcaris, J. excisa, and a few others; slightly branched, in J. pumila, J. lanceolata, and several others; much branched in J. serpyllifolia, J. dilatata, J. Woodsii, &c. In general the branches are irregular in their distribution; but in J. tomentella, J. lævigata, and several others, they originate in a bifarious manner; in J. Tamarisci, they give the stem the appearance of being bipinnate. Nor are innovations unfrequent among the leafy Jungermannæ, giving the fruit the appearance of being lateral, while the flower was terminal. Among the frondose instances of the order, Anthoceros, Sphærocarpus, and J. pinguis, have simple stems; in Riccia glauca, it is somewhat divided at the summit; in J. multifida, J. Blasia, and the genus Marchantia, it is usually very much branched.

The stem is invariably cellulose throughout; and in several instances, the structure is evidently more condensed in the circumference than in the centre;—a proof that, in this order, as well as in the foliose mosses, the most active vegetation is in the centre of the stem.

3. *Leaves.*

As the terms leafy and frondose have already been frequently used in treating of the plants of this order, it would have been unnecessary to mention at present, that both leaves and fronds have place in it;—did it not seem expedient that we state some reason, why we have not employed, to distinguish this order, the term Frondose Musci;—a name for it suggested by the same distinguished botanist, who assigned the name Foliose Musci to the other order.

What we, with, we believe, the greater number of botanists, are disposed to call leaves, occur only in one genus of this order—the genus Jungermannia—to which, however, belongs a much greater number of species, than to all the rest put together. That genus contains, however, also a few frondose species. In the sections containing the leafy species, the leaves originate always by a broad base; and are always continuous in substance with the stem or branch from which they originate, never separating by an articulation. Hence it is contended, that the leaves should be considered as segments of a frond; and that the stipules, with which many leafy Jungermanniæ are furnished, should be regarded as analogous to the scales of ferns.

We feel it difficult to admit this reasoning to be conclusive; first, because it would oblige us to renounce the term leaf, in treating of the foliose or operculate mosses, as well as in the hepatic. In the former order, as well as in the latter, "the leaves and stem are always of one homogeneous cellular substance, perfectly united and continuous; and there is never any solution of continuity between those parts, like the fall of the leaf in other plants, at any part of their growth." Secondly, we cannot admit it, because leaves which never separate from the stem or branches by any articulations, are not uncommon among cotyledoneous plants, particularly the herbaceous species. This then, which we take to be the strongest argument which has been urged against the use of the term leaves, in the description of certain Jungermanniæ, is not less powerful against the operculate musci, to which leaves have never been denied, than against the leafy Jungermanniæ. But it is said to be anomalous, that both leaves and fronds should occur in the same order, and quite unnatural, that they should have place in the same genus. For our own part, we find no greater difficulty in conceiving leafy and frondose species to belong to the same hepatic genus, than in admitting that leafy and leafless species often belong to the same cotyledoneous genera; or that species with a herbaceous, and species with a ligneous stem; species of perennial, and species of annual duration, should be comprehended within the same generic definition. In fine, we think it must appear extremely paradoxical to all, at first, to find the leaf-like expansions of what are usually called the leafy Jungermanniæ, defined to be fronds; we see no good purpose that can be served by the paradox; and therefore we avoid it.

The leaves, then, in this order, never occur on footstalks, they are always sessile, not at all contracted at the base, and always united to the stem or branch which supports them, without articulation. They are often decurrent, as in J. asplenioides. In the bifarious-leaved species, which are the most numerous, they are semiamplexicaul, in an oblique direction, as in J. ventricosa. When, as in J. Hookeri, the leaves are multifarious, they are transversely semiamplexicaul. When bifarious, the leaves are generally imbricated, so as to conceal, to a certain extent, the upper or lower side of the stem.

In direction they vary much, and sometimes not a little in the same species. When multifarious, they generally point toward the summit of the stem, whether it be erect or prostrate. The bifarious species, in general, have the leaves indifferently patent or erect. In J. juniperina, we have a solitary instance of the leaves being secund. In form, the leaves of Jungermanniæ vary much in different species. They are ovate, obovate, orbicular, cuneiform, ligulate, &c. Ovate and orbicular leaves not unfrequently occur on the same plant, as in J. anomala. The apex of the leaves is often rounded, but in J. Dicksoni, &c. it is acute; acuminate in J. juniperina, &c.; very sharp, and almost cuspidate in some states of J. barbata; but in no instance is a leaf furnished with a filiform point.

The leaves of many species are more or less divided from the summit, the divisions varying much both in depth and in number. In many species they are two-lobed, and the lobes are always folded upon each other. In a few instances, the lobes are of equal, or nearly equal size, as in J. resupinata, but in general they are very unequal, and unlike in form. The larger lobe is always plane, or more or less concave, but the smaller varies much more in this respect; it is plane in a considerable number of instances, involute in others; when it has reached its minimum, it is frequently saccate, and appears like a minute thickened part of the other lobe, as in J. Hutchinsiæ. The division between the lobes of the leaf is also very variable. In J. platyphilla, and some other species, the leaf seems rather to have a small lateral involute process, than to be two-lobed; in J. planifolia the two lobes are sometimes completely separated to the very stem. But a regular gradation, through a number of species, may be traced between these extremes. The larger lobe is sometimes again divided, as in J. ciliaris, J. Woodsii; the smaller appears to be always entire.

In general the margins of the leaves are entire, but instances are not wanting in which they are serrated, laciniated, dentate, and even spinoso-dentate.

No instance is known of the leaf of a Jungermannia being furnished with a nerve. In J. albicans there is indeed the appearance of one, but there is no projection on either side of the leaf, as in the nerves of the leaves of the foliose mosses, and the appearance is ocasioned solely by a difference in the form and arrangement of certain of the cells, distributed from the base towards the apex in the central part of the leaf.

The leaves inclosing the anthers, thence termed perigonial leaves, in general differ little from the others, except in being more closely imbricated, and in having a protuberance at the base, where the anthers are situated. These leaves are frequently wanting.

The leaves surrounding the calyx of the female flower, or the perichaetial leaves, in general differ much more from those of the stem. Sometimes, however, they are altogether wanting, as in J. Trichomanis. In J. Hookeri, they are very concave, and entirely surround the young fructifications, supplying the place of a calyx, which is wanting in that species. In J. juniperina, J. scalaris, &c., they are united at the margin, and seem almost converted into a sort of outer calyx. In J. polyanthos and J. sphagni they resemble small scales.

When stipules occur, they are always produced on the lower side of the plant, and generally throughout its whole length, between each pair of leaves. Yet in J. compressa, and J. sphagni, they appear only on the younger branches; and in J. Taylori, J. scalaris, &c. are not easily discovered. They vary much in form, in their margin, in simplicity of division, &c. Their margins are in general plane, but in J. platyphylla and J. Tamarisci, they are recurved.

Such of the Frondose Hepatic mosses as are furnished with a leafy expansion, have it either simple, or lobed, and more or less divided, according as the stem is simple or divided. In J. epiphylla, it is not unfrequently simple, but it occurs also in that species, divided into short unequal lobes. In J. Blasia it is usually very much divided, following the dichotomous or palmate divisions of the stem, (which, in this species, is rarely simple.) The leaf-like expansion of this species, is in general again much lobed in its circumference, and not unfrequently divided in a pinnatifid or bipinnatifid manner. The fronds of J. pubescens, J. Lyellii, and J. hibernica, are divided in a manner very similar to those of the genus Marchantia, to which we shall next proceed, after remarking, that J. pubescens is the only British species of the genus known, that has any downiness on its surface. In Marchantia the fronds are deeply and repeatedly lobed, having a very considerable analogy, in the mode of their division, to the genus Peltidea. In this genus, the stem or nerve is always sufficiently obvious, unless occasionally in feeble plants, which may be found in dry situations, unfavourable to their growth. The fronds of the genus Targionia are usually simple, or but little divided. The upper surface of each is marked with a depressed line, running along the middle of the frond from the base to the apex. Opposite this, on the under surface, a slight elevation is perceptible, marking the situation and direction of the stem.

The genera Anthoceros, Sphærocarpus, Riccia, and Monoclea, as well as the two species of Jungermannia, multifida, and pinguis, have already been noted, as containing only plants which we are disposed to consider as destitute of a leafy expansion. Our reason for this opinion has already been hinted at. In these species no nerve can be traced, nor is there any thing like a short stem between the base of the frond and a tap-root. The nerve, where it can be traced in a frondose plant, is allowed by all to be the stem, or to be representative of it, and we think it has been demonstrated, notwithstanding the frequency of the term *acaulis* in systematic botany, that there is no instance of a truly stemless plant. On this account we give the name of stem to the broad frondose expansion in the plants just mentioned; though we admit, that this part, which we term stem, performs also the function of leaves in regard to these plants, just as the succulent leafless stems of various Cacti, Euphorbiæ, Stapeliæ, &c. perform the part of leaves in regard to them.

REPRODUCTIVE ORGANS.

1. *Flowers and Fruit.*

As no instance is known of an united flower in any hepatic moss, we shall describe first the flowers containing the stamens. These have already been stated to be destitute of a calyx, or any other proper covering. By Hedwig, substances differing much in form and structure, were described as stamens of the Jungermanniæ. In the leafy species may be found not unfrequently, on the upper leaves, and sometimes on the summits of the stems, a somewhat spherical capitulum, consisting of minute globules, which are more or less pellucid, not supported on a footstalk, and of which no internal organization has been traced. They vary in form, being sometimes ovate, sometimes angular. On their falling off, the leaves and ends of the stems frequently appear truncated or jagged, as if by the loss of a part of their substance. Hedwig regarded this as no unlikely consequence of their having supported male flowers; but Dr. Hooker has, with great probability, conjectured that each of these globules may hence be considered as a cell of the leaf or stem.

The true anthers of Jungermanniæ originate from the stem or branches. In the leafy species they are usually inclosed in densely imbricated leaves, the number within each leaf being indefinite, and varying from one to five or six. In a few instances the perigonial leaves (or those next the anthers) are patent, and in several species the anthers are without any covering. They are, in the leafy species, always supported on a whitish, pellucid, very delicate filament, and are spherical in form, having much resemblance to those of the genus Sphagnum. In the frondose species, the filament is in some instances very short, as in J. pinguis; in others it is altogether wanting, as in J. epiphylla, and J. Blasia. In these two last mentioned species, indeed, the anthers are imbedded; —in J. Blasia, in the substance of the nerve; in J. epiphylla in a lateral process, have some analogy to the receptacle of the male flowers of the genus Marchantia. In J. Blasia the usual spherical form of the anther, is exchanged for an oval. In some frondose species, the anthers are found always on the upper surface of the frond, as in J. Lyellii and J. hibernica; in others, always on the lower surface, as in J. furcata and J. pubescens.

In structure, the anthers of Jungermanniæ consist of a membranous covering containing a fluid, with a granulated substance swimming in it, the granules being usually of an olive brown or greyish colour; but in J. pusilla they are yellow, and orange coloured in J. Hookeri. It would appear, that before the maturity of the anther the fluid is absorbed, and the granules become a farinaceous pollen—at least such a pollen seems to be represented by Hedwig, as seen by him to escape from an anther of J. epiphylla. *Theor Generat. et Fructif. Plant. Crypt.—2d ed. tab.* xxiv. Several monœcious species of Jungermanniæ are known, but by much the greater number of them is diœcious.

With the exception of M. androgyna, and according to Wahlenberg, M. hemisphaerica, in which male and female flowers occur on the same plant, all the species of Marchantia are diœcious. The anthers, in all the species in which they have been discovered, are inclosed within a common receptacle, which varies considerably in form in different species. In M. polymorpha, it is peltate or concave, nearly entire in the margin, scaly on the under surface, and striated, with nine or ten furrows, marked with papillæform projections on the upper surface, and supported on a stalk, like the receptacle containing the female fructification. In M. conica and M. androgyna, it is wart-shaped and sessile, with numerous papillæform projections on the upper surface, and at last becoming concave. In both of these forms of the receptacle, the anthers are disclosed by a perpendicular section near the middle of the receptacle. They are of an oblongo-ovate form, with a very short filament. They appear to be surrounded with a transparent jointed ring, and to contain a granular substance. According to Micheli, the anthers of M. conica at last dissolve into a milky fluid, which, under the microscope, appears to consist of a thin transparent colourless fluid, with numerous white particles swimming in it.

Of the genus Targionia, the anthers can scarcely be said to be known. Within the meshes of that very thin, delicate, reticulated membrane, which lines the calyx of the fruit, Sprengel perceived minute granular bodies, respecting the nature of which he gives no positive opinion, but seems inclined to take them for anthers. Till they be examined by dissection, and their external characters be more accurately ascertained, their true nature must remain altogether problematical; but, supposing them to be really the anthers, this genus must be admitted to exhibit a nearer approach to an united flower, than any other of the Hepatic Mosses.

On the fronds of Anthoceros, and usually near to the female flowers, may be perceived several minute, slightly elevated, greenish yellow spots. These, when examined under the microscope, are found to contain several ovate corpuscles, situated immediately under the cuticle. When these corpuscles have attained a certain size, the cuticle covering them opens, is retracted on every side, and forms an oval margin at a certain distance around them. It would appear, that sometimes a part of the cuticle adheres to these corpuscles, forming a sort of crown to them. The corpuscles of an ovate figure, surrounded by a pellucid jointed ring, contain a granular matter, and are supported each on a short pellucid stalk. There can be no doubt that these are the anthers of this genus. When the pollen has escaped, they shrivel, and acquire a darker colour.

Amid the projecting points with which the upper surface of Riccia glauca is studded, shining white globules are easily observed. One or two of these being gently removed, and examined in a drop of water under a high power of the microscope, they are found to contain a granular mass. Each is supported on a dark-coloured filament, and instead of the usual pellucid jointed ring, is surrounded with a dark border. These seem to be the stamens of this species. The fructification of the other Ricciæ, at least of the other British species, is quite unknown.

The stamens of the genera Sphærocarpus and Monoclea, are altogether unknown.

From the female fructification of the hepatic musci the calyx is rarely absent. Yet instances of this deficiency, as already stated, are not wanting in the genus Jungermannia, no calyx occurring in J. concinnata, or J. Hookeri. In a few other species, as J. juniperina, J. scalaris, &c. a sort of calyx is formed by the union of the perichætial leaves, (or those next the germen.) It is very small in comparison of the calyptra, seldom reaching to half its length. It is usually single; but instances of a double calyx occur in J. Lyellii, J. hybernica, J. phyllanthus, J. flabellata, and J. hymenophyllum, all frondose species. In most cases it is tubular, or somewhat ventricose; the mouth somewhat plicate. Other forms of the calyx, however, are found in species of very common occurrence; thus in J. epiphylla, multifida, and pinguis, it is cup-shaped; in J. furcata like a scale. In J. asplenioides it is somewhat flattened, and, before the capsule escapes, is curved at the apex, and slit down a little on one side. In J. gigantea it is very much compressed at the mouth. The mouth of the calyx is generally roundish, in many species toothed; four-cleft in J. sphærocarpa, ciliate in J. connivens, J. gigantea, &c. flattened and truncate in J. asplenioides, &c. In substance it in general resembles the leaves; but it is membranaceous in J. Blasia, rather carnose in J. tomentella and J. coalita; very carnose in J. Trichomanis, &c. Its surface is in general smooth; but in J. dilatata and falcata it is tuberculated. In situation it is either terminal, lateral, on short lateral branches, or on short branches at the base of the shoots. When lateral, it sometimes arises from the upper side of the stem, as in J. pusilla; at other times from the lower side, as in J. sphagni.

In all the British species the calyx is inserted on its base, and hence upright, except in J. Trichomanis and J. viticulosa, in which it is attached by the side of the mouth, pendent, and buried in the earth. In J. saccata of New Zealand, the calyx has a similar attachment; but as it arises from the summits of upright branches, it is never concealed in the earth.

In Marchantia (at least in the species polymorpha and conica) the calyx is tubular; and much longer than in the Jungermanniae, only the summit of the style appearing beyond it, when the germen begins to enlarge, at which time it becomes flagon-shaped. It is of a very delicate membranaceous texture; the mouth at first nearly entire, but it is said to be divided afterwards in M. chenopoda, M. cruciata, and M. polymorpha, into four segments, and in the other species into a greater number. Its colour is brownish. Besides this proper calyx, M. conica and M. cruciata are furnished with what may perhaps be termed a common one in a cup-shaped process, out of which the peduncle supporting the common receptacle arises.

Some distinguished botanists, after Linnæus, term the common receptacle of the female fructification, which forms the characteristic mark of the genus Marchantia, a common calyx. But this is contrary to the analogy of all the other hepatic mosses, to the calyces of none of which it has the least resemblance; and it is very inconvenient in regard to this genus itself, as the supposed common calyx is totally unlike the proper calyx. The little cup at the base of the fruitstalk seems to us much better to merit the appellation; and there can surely be no doubt, that the common receptacle is quite a peculiar organ. It is always supported on a footstalk. In form it is stellated, hemispherical or conical, usually more or less lobed. In M. chenopoda of the West Indies, it appears as if halved, its three, four, or five acuminated segments being directed to one side only. The flowers are always on the lower side of the receptacles, and occur chiefly towards the summits of the lobes or segments.

In Targonia, what appears to be the calyx consists of a double membrane, the exterior of a reddish purple, the interior more delicate, white, with hexagonal meshes, in which meshes the supposed anthers of this moss are situated.

The calyx of Anthoceros is cylindrical, somewhat elongated; its orifice toothed, and at last reflected; its structure exactly resembles that of the frond.

The calyx of Sphærocarpus is inversely pear-shaped, not above a line in length, with a contracted orifice at the summit. It is described by Dillenius and Micheli as at last splitting into two segments,—a division which does not appear to have been afterwards observed; and hence many modern botanists suspect some fallacy in the observation of these two illustrious authors on this particular point. In structure, the calyx exactly resembles the frond.

In Riccia glauca, the whole pistil in its younger state, with the exception of its apex, is immersed in the substance of the frond. Hence a calyx seems scarcely to be necessary to protect the fruit of this plant; and none has been discovered. Monoclea is also destitute of a calyx, the cavity in the frond, from which the fruitstalk originates, probably serving in its stead.

The number of pistilla which occur within one calyx varies in different genera, and even in different species of the same genus. In Jungermannia, from three to eight or ten have been found in one calyx. In form they are generally linear or lanceolate; but in J. pinguis, J. furcata, and J. multifida, they are short and ovate. Their colour is whitish or pale grey, with reddish longitudinal streaks. Generally one, sometimes two of these pistilla become fertile. The germen then swells and acquires an olive colour. The style, varying in length in different species, soon decays. The stigma is somewhat wider than the style.

In Marchantia polymorpha, two or three pistilla occur within each calyx. In the earliest period at which they have been observed, the germen is conical and olive brown. Never above one pistil in each calyx seems to become fertile. The style is brownish, and of considerable length; the stigma scarcely wider than the style.

The calyx of Targionia contains always several pistils, of which only one becomes fertile. The germen is oval, nearly sessile; the style terminal and subulate, tubular; the stigma concave.

In Anthoceros each calyx seems to contain only a single pistil, which is cylindrical, tapering towards the summit, on which appears a brownish substance consisting of numerous filaments, and this again is surmounted by a short style of the same colour. The stigma is not at all enlarged. The form of the pistil and of the fruit of Anthoceros, is that of a little *horn*, or tusk; and hence the generic name. In Riccia glauca the germen, which is completely immersed in the frond till considerably advanced, is of a roundish form; the style, rather short, of a dark purple colour, projects slightly above the surface of the frond; the stigma appears truncated. This is the only hepatic moss in which the style is known to persist.

The pistils of Sphærocarpus and Monoclea are completely unknown.

The calyptra, or exterior covering of the pistil, is known to exist in every hepatic moss, of which the fruit has been seen; with the exception of Sphærocarpus, of which the flower is completely unknown. As in the foliose mosses, it is attached by its base to the receptacle; free around the germen; inseparably united to the style; and usually expanded at the summit, forming a considerable portion of the stigma. In several instances, however, as already mentioned, the stigma is not wider than the style. In texture it is usually membranaceous; but in some of the frondose Jungermanniæ, such as J. epiphylla, J. pinguis, J. multifida, and J. furcata, and various foreign species, it is subcarnose. Its surface is usually smooth; but in J. multifida it is tuberculated, and in J. furcata hispid. In the other frondose genera it is usually membranaceous and smooth. In Anthoceros it seems to consist of a number of dark coloured filaments.

At a certain period after the flower, a passage through the calyptra is forced, either in consequence of the elongation of a peculiar receptacle, like that of the foliose mosses, termed fruitstalk, or in consequence of the enlargement of the fruit itself. In the Jungermanniæ the fruitstalk varies very much, being very long in J. epiphylla, and J. pinguis; in the former of which it sometimes attains the length of three inches: while in J. platyphylla, J. scolopendra, &c. it merely rises above the very short calyx, and probably, in these species, is seldom more than two, or at most three lines in length. The fruitstalks of the Jungermanniæ consist of an extremely delicate, lax, cellular tissue, usually of a semi-pellucid whiteness. They are of remarkably rapid growth, and equally rapid decay. In J. epiphylla, for instance, if in the evening a capsule be perceived which has just newly burst through the calyptra, and the same plant be visited again next morning, (supposing the night to have been mild and moist,) the fruitstalk will be found to have attained its full length. Between eight and ten in that morning probably the capsule will open; and by a little past eleven the fruitstalk will begin to decay. The duration of that of J. Blasia is perhaps even shorter. On account of this extreme fugaciousness, the fruit of some of the Jungermanniæ is much more difficult to be met with than that of the foliose mosses.

In Marchantia the fruitstalk is so extremely short, that it may almost be said to be wanting. It differs in no essential respect from that of Jungermannia. It is of course an organ extremely different from the peduncle or stalk which supports the common receptacle.

In Monoclea the peduncle reaches the height of about an inch and a half; is succulent, somewhat carnose; of a sordid yellow. In some instances a single fruitstalk, in others three of them, arise from the same cavity in the frond. In the other hepatic genera, Anthoceros, Sphærocarpus, Targionia, and Riccia, the fruit is sessile.

The fruit of all the Hepatic mosses, with the exception perhaps of Sphærocarpus, is capsular.

In the genus Jungermannia, before the capsule has escaped the calyptra, it is of an ovate figure, without any appearance of sutures. At this early stage it consists interiorly of cellular tissue, containing numerous dark-coloured granules, with numerous twisted brown lines intermingled. When it has emerged from the calyptra, the capsule hardens; the sutures become evident; the pulp is absorbed; and the capsule contains only the granules become seeds, and the twisted brown lines become spiral filaments. The texture of the calyx is usually corneous; but in several species it is membranaceous and pale brown, as in J. Mackaii, J. pusilla, &c.; membranaceous, white, and transparent, in J. hamatifolia, J. calyptrifolia, and some others. In general, the capsule divides to the very base into four valves, which become quite expanded; but in J. calyptrifolia, J. minutissima, &c. the valves do not reach above half the length of the capsule; and in J. Hookeri, J. Lyellii, and some others, have five valves instead of the usual number. In J. pusilla, it is altogether irregular in the mode of opening; a singular anomaly. In J. Trichomanis, the number of valves is as usual four, divided to the very base; but they are twisted spirally in a singular manner.

The spiral filaments, (elateres,) which occur always intermingled with the seeds of the Jungermanniæ, and some other hepatic genera, consist, in some instances, of a single thread, twisted upon itself; in other instances, of two threads, enveloped in a thin, pellucid, tubular membrane. The mode of their attachment is in many instances quite problematical, as they are always found quite loose at both ends, intermingled among the seeds. In J. Hookeri, J. furcata, &c. they are formed of a single thread, and remain, after the discharge of the seeds, attached to the extremity of the valves of the capsule. In J. flabellata, J. serpyllifolia, &c. the attachment is the same; but each spiral filament consists of a double helix, or twisted thread. In J. epiphylla, the filaments remain attached, in a thick tuft, to the centre of the capsule, opposite the insertion of the fruitstalk.

The capsule of Marchantia is very similar in structure to that of Jungermannia. At maturity, the four valves of the capsule roll backwards, and disclose a great number of spiral filaments, with the seeds intermingled. According to Hedwig's delineation, in M. conica, the spiral filaments seem to be irregular in the number of their helices, two, three, or four, occurring indifferently within the pellucid membrane, in spiral filaments taken from the same capsule. In M. polymorpha, the filaments consist always of a double helix. In Monoclea, which, in the structure of its fruit approaches the nearest to the two genera already treated of, the capsule is oblongo-cylindraceous, striated, inclined; opening on the back, or upper part, by a *single valve*. Each capsule contains numerous seeds and spiral filaments. The filaments consist each of a double helix. M. Forsteri is the only hepatic moss with a univalve capsule, hitherto discovered. In Anthoceros and Targionia, the capsules are bivalve. In Anthoceros the capsule splits longitudinally from the summit, as if by the separation of the valves of a silique, and discloses numerous seeds, which are supposed to have been attached to a very obvious cylindrical central columella, as well as to the valves; and numerous elateres, or seed dispersers, of a structure very different from the spiral filaments of the preceding genera. They sometimes are of one piece, of a length probably sufficient to measure twice the circumference of a seed, rounded on the exterior side, and flat on the interior, with the end somewhat incrassated, bent in the form of a semicircle, and each seizing one of the seeds with its two extremities. More frequently they are of two pieces, united by a joint; and seem extremely well fitted for dispersing the seeds with elasticity.

The globose capsule of Targionia is situated on the lower surface of the frond; and at maturity splits vertically into two hemispherical valves. It contains numerous very minute seeds, combined by threads into a dense globular mass. In this genus elateres, or seed dispersers, are altogether wanting.

The pericarp of Sphærocarpus is unknown. In the bottom of the calyx, there appears at maturity a dense mass of extremely minute seeds, combined into a globular form by numerous threads, as in Targionia. In Riccia glauca the capsule, having emerged some time before maturity from the substance of the frond in which the germen was lodged, appears of a roundish form. At maturity the upper part of the capsule separates, and a mass of dark-coloured seeds comes in view. This is the only known hepatic moss, having an obvious pericarp, which is not valvular.

Seeds of Hepatic Mosses.

These vary much in form, size, surface, and colour, in different genera, and even species of the same genus. In Jungermannia, they are usually spherical; but in J. serpyllifolia, J. minutissima, and J. calyptrifolia, they are oblong, somewhat angular in the two latter; in J. epiphylla, they are irregular in form, but usually more or less oblong or ovate. In size they vary very much, sometimes a small capsule containing a great number of seeds, while a much larger one contains comparatively few. And, as in the foliose mosses, some of the minutest species are noted for the largeness of their seeds. Thus J. minutissima and J. calyptrifolia, two microscopic species, have both large seeds compared with the size of the plants and of the capsule; while in J. Trichomanis they are small and numerous. Their surface is usually smooth; yet in J. Hutchinsiæ, they are marked with spots which appear to be minute tubercles; in J. dilatata, and J. Tamarisci, they are tuberculated; and in J. pusilla, they are echinated. Their colour is usually some shade of brown, varying from yellowish-brown to olive-brown; but different shades of green are also far from uncommon. In the capsule, as well as when falling out, they usually appear quite separate and unconnected; but those of J. Hookeri, and J. Blasia, are usually enveloped three together, in a pellucid membrane. In J. Blasia, parcels of two, and of four are also found within one membrane; and it seems to give way before the escape of the seeds as they fall out separately. In J. Hookeri the membrane is no longer visible when the seeds are quite mature; yet as they usually fall out in threes, it seems probable that the membrane continues to exist.

In Marchantia also, the seeds are of a spherical form, at least in the species polymorpha and conica, the species which come most frequently under observation in this neighbourhood. In M. conica, their surface is covered with minute spots, which probably are tubercles.

The seeds of Monoclea and Anthoceros are also nearly spherical. In Monoclea their surface is smooth, in Anthoceros it is echinated.

The seeds of Riccia glauca appear, at an early period, like white smooth globules. When more advanced, they become flattened, of a greenish colour, surrounded by a pellucid white line. At maturity, they become dark-brown, hemispherical, or in some instances nearly ovate, with a prominent point always at one, and sometimes at both extremities.

The germination of the seeds of hepatic mosses has been observed in species of the two genera Jungermannia and Marchantia.

In April 1780, Hedwig sowed some of the seeds of J. epiphylla, by shaking some of the mature capsules over a flowerpot, the earth in which had been properly prepared for this experiment. After the lapse of a few days, they began to swell, and afterwards, from the narrower and lighter coloured extremity, a white, simple, and very pellucid root proceeded. The upper part of the seeds became at first reticulated, and afterwards they expanded into perfect plants. Thus it has been satisfactorily proved, that in Jungermannia, the little granules contained in the capsules are really seeds.

On the germination of Marchantia, experiments were made by Neckar, as early as 1772. In 1779, Hedwig repeated the experiment with the seeds of M. polymorpha. Having prepared a flowerpot, containing that sort of mould which he reckoned most agreeable to this species, and in a due degree of moisture, he cautiously shook over it some stellated receptacles, of which the capsules were open. The pots were then covered with branches of boxwood, which had been well washed in spring-water. In eight days after the sowing, the whole earth in the flowerpot assumed a greenish hue, afterwards distinct plants could be easily traced; and in the following spring, both peltate and stellated receptacles were produced by them.

2. *Of Gemmæ, or Buds.*

In the genus Jungermannia, these appear to occur on only a few species. In J. minutissima, J. calyptrifolia, and some other minute species, they seem to be produced on the stems; in J. complanata, on the margins of the leaves; in J. furcata on the extremity of the frond; and in J. Blasia within proper tubular receptacles These receptacles were formerly considered as the fruit of this plant, which was accordingly, from the time of Linnæus downwards, till the publication of the last number of Dr. Hooker's admirable monograph of the British Jungermanniæ, considered as of a distinct genus termed Blasia. Specimens of this plant, with capsules, had been gathered long before by Mr. Dickson, on the shores of Loch Tay, who took it for a new Jungermannia. About the same time that these were communicated to Dr. Hooker, specimens without capsules were sent to him by Swartz. The marginal gemmæ in both immediately attracted his attention. Mr. Lyell found the plant at Kinnordy, and having watched its progress, he obtained specimens with young fruit, not yet burst from the the calyptra, and soon after, the same gentleman sent from Ambleside a specimen with the capsule burst from the frond. And Dr. Taylor, now of Cork, found ripe capsules on the mountains at Loch Bray, in March, 1814. Thus was the genus Blasia erased from among vegetables, and the species formerly known by the name of Blasia pusilla became Jungermannia Blasia.

In structure, the gemmæ of Jungermanniæ resemble the leaves of the species which produce them. They vary in form, being spherical in J. Blasia, J. calyptrifolia, and some others, and in J. complanata and J. furcata, somewhat oblong. Those of J. Blasia are furnished with roots, even before their escape from the proper receptacle, and in that species, as well as in J. furcata, their progress towards perfect fronds may be easily traced.

The gemmæ of Marchantia are contained within proper cup-shaped receptacles. These receptacles appear at first as minute slightly elevated spots, but after having increased somewhat in size, they open, and disclose a number of oblong substances, tapering towards both extremities, each of which, in due time, falls out of the receptacle, and in favourable circumstances, becomes a perfect plant. On the sterile fronds of M. polymorpha, these cup-shaped receptacles of gemmæ are often very numerous. No gemmæ have hitherto been detected on any other of the hepatic musci.

Generic Distribution of the Hepatic or Deoperculate Mosses.

The only alterations which have taken place in the generic distribution of this family since the time of Linnæus, are, the blotting from the list the genus Blasia, as already mentioned under the article Gemmæ, a late alteration, and the discovery, also recent, of the genus Monoclea. Indeed, with these exceptions, and the very important one of the discovery of many new species of Jungermannia, the hepatic mosses remain in a state very little different from that in which they were left by Dillenius and Micheli.

* *Furnished with Spiral Filaments.*

I. Jungermannia. No common receptacle of the Fruit. Capsule quadrivalve, seated on a fruitstalk longer than the calyx. No columella.

This very extensive genus contains no fewer than 81 British species; and 42 rare foreign ones, of which 32 had not been previously published, have been figured and described by Dr. Hooker in the *Musci Exotici.* The genus is divided into primary sections, according as the species are leafy or frondose. The leafy species are subdivided into such as have no stipules, and such as are furnished with these appendages. The exstipulated species are again subdivided, according to the insertion of the leaves; whether it be (1) multifariously, or indifferently, on all sides of the stem, as in J. julacea; or (2) bifariously, on two opposite sides of the stem only. This section, containing many species, has them arranged under the heads, (*a*) leaves undivided, as in J. asplenioides; (*b*) leaves emarginate or bifid, the segments equal; as in J. emarginata, J. bicuspidata; (*c*) leaves divided into three or four equal segments, as in J. pusilla, J. capitata; (*d*) leaves bifid, the segments unequal, and doubled; as in J. nemorosa, J. complanata. The stipulate species are subdivided, (1) into such as have the leaves entire, or with a few scattered notches; as in J. anomala, J. Trichomanis; (2) such as have the leaves divided into two or three equal segments; as in J. bidentata, J. trilobata; (3) such as have the leaves bifid, the segments unequal, and folded on each other; and this section is subdivided into (*a*) species having the lower, or smaller segment plain; as in J. platyphylla; (*b*) having the lower or smaller segment involute, as in J. calyptrifolia; (*c*) having the lower or smaller segment saccate, as in J. Hutchinsiæ, J. Tamarisci.

These sections and subsections exhaust the leafy species. The Frondose species are divided primarily, into, (1) such as are nerveless, as J. pinguis, J. multifida, (2) such as are furnished with a nerve; and this section is subdivided according as (*a*) the calyx is single, for instance, in J. Blasia, J. epiphylla, (*b*) the calyx is double, as in J. Lyellii, J. hibernica.

The neighbourhood of Edinburgh abounds in Jungermanniæ; J. Blasia has been gathered in fruit in Peeblesshire, in the autumn of 1818 and 1819; and some very rare and curious species, as J. setiformis, J. Doniana, J. albescens, have been discovered in Britain, hitherto only on the Scottish Alps.

II. Monoclea. No common receptacle of the fruit. Capsule univalve, opening longitudinally on one side; seated on a fruitstalk longer than the calyx.

Of this interesting genus, only one species, M. Forsteri, is known, which was gathered in some one of the South Sea Islands, by Mr. G. Forster. It differs from Anthoceros. to which genus Mr. Forster had reduced it, in possessing true spiral filaments, in the want of a columella and of a calyx, as well as in being univalve.

III. Marchantia. Receptacle of the male flowers peltate or wart-like, with numerous antheræ embedded in its disc. Female flowers. Common receptacle peltate, flowering beneath. Capsules opening at the summit by revolute valves.

Of this genus only eight species appear to be known, all of which, but one, were enumerated by Linnæus; and no fewer than five of them are indigenous to Britain. Of these, M. cruciata, M. hemisphærica, and M. androgyna, are rare. M. polymorpha is extremely common, and is one of the plagues of gardeners, over-running their flower-pots and beds. M. conica is plentiful by the sides of streams; but rather capricious in producing its fruit, which, when it occurs, is usually mature in March or April.

*** Furnished with Elastic Seed Dispersers, not Spiral. Never with a common receptacle.*

IV. Anthoceros. Male flowers, scattered, wartlike. Female. Calyx tubular. Capsule subulate. Seeds numerous, rough, attached to the valves, as well as to the columella.

Of this genus, three species, A. punctatus, A. laevis, (or major,) and A. multifidus, are known; of which the two former are indigenous to Britain. They grow in clover and turnip fields, and produce fruit in winter.

**** Unfurnished with Elateres, or Seed Dispersers. No common receptacle.*

V. Targionia. Capsule globose, of two concave valves. Seeds numerous, combined by fibres into a globe.

Only one species is known, T. hypophylla; which was first found in Italy, and figured and described by Micheli. Within these few years it has been ascertained to be a British species. It grows on the sides of dripping rocks, producing fruit in spring.

VI. Sphærocarpus. Calyx monophyllous, inflated, entire. Seeds very numerous, collected into a globe, in the bottom of the calyx.

Contains only one species, Sph. terrestris; which grows in the same places, and at the same time, with Riccia glauca—though it is apt to be mistaken, on a cursory view, for a Phascum. Its glaucous hue distinguishes it, at first glance, to those who have once seen it.

VII. Riccia. Male flowers, scattered, wartlike.

Female, germen globose, embedded, with the lower part of the style in the frond. Capsule exposed, globose, crowned with the style. Seeds numerous, elliptical.

Of this genus, five species are usually enumerated; of which three, R. glauca, R. natans, and R. fluitans, are British. R. natans and R. fluitans, uncertain species, as their fruit is unknown, are rare, and occur among duckweed, &c. floating on the surface of stagnant pools. R. glauca is very abundant in croft lands and clover fields, in the beginning of winter.

Excluding the genus Jungermannia, which has been already so well illustrated by Dr. Hooker, there is, within the ample bounds of systematic botany, perhaps no tribe of plants more inviting, as the subject of a short monograph, than the hepatic mosses. In regard to them, the best treatises, hitherto published, not unfrequently give statements directly opposite, and in general without the slightest intimation that a difference of opinion exists on the points in question. Several of these discrepancies, the monographist, having the plant before him, with the proper instruments, might remove for ever without much difficulty. Some of the species are indeed not easily obtained; but this surely need be no impediment to the undertaking, considering the liberality with which all who are known in botany, in the present age, communicate specimens, and elucidations, whenever they see reason to believe that it may be for the advancement of the science; and even, in very many instances, for the mere gratification of an amateur.

We cannot avoid expressing at present our regret, that the distinguished author of the work entitled *Musci Exotici*, to which we have so often referred, should have discontinued it, in order to write popular books for home consumption. We trust, that his admirable talent for description and discrimination, and his inimitable pencil, will soon be again directed to objects more worthy of them. We are aware of the great importance of good elementary works; but for one who could continue the work just alluded to, or proceed on the same plan, with the new series of the Flora Londinensis, there are undoubtedly several quite adequate to supply any want of the other sort, that can be at present felt. On the same account, we regret the abrupt conclusion of the *Historia Fucorum*, by another distinguished author; and though we cannot doubt, that a work on antiquities from his pen will be minutely accurate, and equally learned, elegant, and amusing; yet the world certainly abounds much more in good antiquarians, though even they are not exceedingly plentiful, than in Cryptogamists, such as he is.

New Arrangement of the Jungermanniæ.

We shall conclude this article, with a brief notice of a new arrangement of the genûs Jungermannia, which has been proposed by Signior Giuseppe Raddi, of Florence, in a paper on the Jungermanniæ of Tuscany, inserted in the Memoirs of the Italian Society, Vol. xviii. Part i. division, Physics.

Signior Raddi's paper is altogether theoretical, and is to be considered, we conceive, as the Prodromus of a work on the rare Cryptogamic plants of Tuscany, which he announces in it. The thirty-seven species which he has characterised, we take to be intended merely as instances of his new genera; as it is inconceivable that the Florentine territory should not produce a greater number; and though there are several rare species among them, they have no pretensions, when viewed together, to the character of a selection of rare species.

After stating, that ever since the days of Micheli, the necessity of some subdivision of the genus had been felt by various learned and celebrated botanists; and noticing slightly Micheli's own subdivision of it into the genera Jungermannia, Muscoides, and Marsilea, he proceeds to remark, that "the difference between the species of Jungermannia is so great, that many of them, as J. viticulosa, J. asplenioides, J. platyphylla, J. lævigata, J. emarginata, &c. are so nearly related to the frondose (foliose) mosses, as to agree with them in their natural characters, and even in many of the artificial marks employed to discriminate them, so that they absolutely merit a place in that family." It is unfortunate, that we are not furnished with a character, either natural or artificial, of any foliose moss; but certainly Signior Raddi must allude to characters of the plants of that family very different from any with which we are acquainted, if they enable him to blend the leafy but deoperculate Jungermanniæ with the leafy and operculate mosses. We wonder that he has not pressed Andræa, and perhaps J. julacea, into his service, as connecting links; as they surely have more affinity in habit than the Jungermanniæ, which he has instanced, and any operculate moss. His proofs that the Jungermanniæ should be blended with the operculate mosses, are these; both are branched, and vary in the number of their branches; both produce roots with great facility; some species of operculate mosses, as Bryum androgynum, Tetraphis pellucida, &c. as well as Jungermanniæ, produce on the end of the stem powdery heads, which he takes to be collections of buds; and he reminds us, that the ovaria of both have a calyptra. We are sorry that he has stopt short, after merely commencing the most interesting part of his proof; and cannot help considering what he has advanced as altogether nugatory, unless further supported.

But to proceed to Signior Raddi's arrangement. It is founded chiefly on the structure, consistency, and insertion of the calyx, calyptra, capsule, and even the antheræ, so that its basis is considerably more extensive than that formerly proposed by Hedwig; and according to these, the genus Jungermannia of authors is divided into ten new genera, of which the following are the names and characters:

I. Bellincinia. Calyx compressed, laciniato-dentate, sub-bilabiate, smooth. Calyptra of one piece, membranous, pellucid, its border variously divided. Capsule ovate, or between ovate and roundish, dividing into four equal valves, supported on a delicate, pellucid, cellulose footstalk, the growth of which is remarkably rapid, as in the following genera.

The only species instanced is B. montana; J. lævigata of Hooker's British Jungermanniæ, t. xxxv.

II. Antoiria. Calyx compressed, bilabiate; the lips quite entire, somewhat rounded. Calyptra of one piece, its border variously divided. Capsule roundish, dividing into four equal valves.

Spikelets ovato-lanceolate, formed of imbricated convex scales, containing the roundish antheræ, on a different individual.

Ant. vulgaris, or J. platyphylla of authors, is the only instance.

III. Frullania. Calyx nearly triangular, divided at the summit into three roundish apiculate segments; plano-convex above, with sometimes prominent stripes, and more or less besprinkled with minute tubercles. Calyptra of one piece, the limb variously divided. Capsule ovate, or between ovate and roundish, quadrivalve. Spikelet oval, formed by imbricated convex scales containing the antheræ.

Two species are instanced, F. major (J. dilatata) and F. minor (J. Tamarisci.)

IV. Candollea. Calyx more or less compressed, truncated, adhering to the stem by its base. Calyptra of one piece, its border variously divided. Capsule ovate or roundish, dividing into four equal valves.

Antheræ subcarnose, irregular in their position, being sometimes on the margin of the leaves; at other times on the summit of the terminal leaves; and usually on a distinct individual.

C. asplenioides, (J. asplenioides,) C. carinata, supposed to be J. compacta of Roth, or J. resupinata of Hooker, C. nemorosa, (J. nemorosa,) and C. complanata, (J. complanata,) are four species given as instances of this genus.

V. Jungermannia. Calyx monophyllous, membranous, tubular, adhering to the stem by its base. Calyptra of one piece, membranous, pellucid, bearing the style, its border variously divided. Capsule ovate or roundish, covered by the calyptra while it remains in the calyx, dividing into four equal valves. Seeds numerous, minute, adhering to the whole inner surface of the valves by means of very slender elastic filaments.

Antheræ without any covering, placed sometimes on the margins or summits of the leaves, at other times forming a roundish mass on the end of the stem, and usually occurring on a distinct individual.

This new genus is arranged into four primary divisions, each of which is again divided into sections, and sometimes into subsections: the first division, entitled, (A.) Leaves without lobes or stipules, consists of the following sections: first, Leaves entire. Contains J. poanthos, J. scalaris, J. lanceolata, and J. tenerrima, which last is said to be the J. gracillima of English botany: the second section, entiled, Leaves emarginate, two-lobed, or bifid, is subdivided, according as (α) the margin is quite entire, *i. e.* without teeth, as in J. connivens, and five other species, not well ascertained; or as it is (β) toothed, of which the only instance is J. dentata of Signior Raddi, a species of which he thinks J. Turneri to be probably a variety: the third section contains species with more than two teeth, or divisions, of which J. quinquedentata (J. barbata, Hooker, t. lxx.) is the only instance.

The second primary division (B.) contains the species having the leaves lobed, but no stipules.

Its first section contains the species with the smaller lobe uppermost, as J. falcata of Raddi, (J. albicans) his only instance. Its second, the species with the smaller lobe undermost, of which J. inconspicua of Raddi, supposed to be J. minutissima, is the only instance.

The third primary division (C.) contains the species having the leaves two-lobed, and furnished with stipules. As only one species is instanced under this division, it was unnecessary to give any title of a section; yet we find section first, Leaves entire, containing J. serpyllifolia.

The fourth and last primary division (D.) contains the stipulate species, of which the leaves are not two-lobed.

Its first section, in which the leaves are entire, contains only J. viticulosa. Its second, in which the leaves are emarginate, or bidentate, contains only J. bidentata. Its third, in which the leaves are terminated by more than two teeth or divisions, contains J. trilobata and J. reptans.

VI. Fossombronia. Calyx monophyllous, subcampanulate. Calyptra of one piece, bearing the style, its border variously divided. Capsule roundish, splitting into irregular segments.

Antheræ succulent, pedunculate, situated at the lower part of the stem in a distinct individual.

It contains only F. angulosa, (J. Pusilla, Hooker, t. lxix.)

VII. Calypogeja. Calyx cylindrical, carnose adhering to the stem by the side of its mouth, and buried in the earth. Calyptra of one piece, its border divided into two or three irregular segments. Capsule cylindrical, obtuse, dividing into four equal linear valves.

Male flowers as in Jungermannia.

It contains C. ericetorum of Raddi, a new, or supposed new species, C. flagellifera, (J. palustris repens, &c. of Micheli, Fig. 5.) C. fissa, (J. Trichomanis.)

VIII. Metzgeria. Calyx ascending, membranaceous, turbinate, and adhering by its base to the lower side of the frond. Calyptra of one piece, its border variously divided. Capsule roundish, dividing into four equal valves. Seeds minute, adhering by very slender elastic filaments to the inner surface of the valves at their apex. Ovate or globose corpuscles, which are perhaps the male fructification, are scattered over the upper surface of a distinct frond.

Contains two species, M. glabra (J. furcata) and M. pubescens (J. pubescens.)

IX. Röemeria. Calyx, or rather Calyptra, resembling a calyx, ascending, carnose, almost truncated at the apex, and slightly attenuated at the base, by which it adheres to the lower surface of the frond.

Capsule oblong, dividing into four equal valves. Seeds numerous, adhering by very slender and elastic filaments to the inner surface of the valves at their apex. Supposed anthers scattered on the upper surface of a distinct frond.

Contains two species, R. multifida, R. palmata, (both of which are merely J. multifida,) and R. pinguis, (J. pinguis.)

X. Pellia. Calyx arising from the upper surface of the frond, its limb somewhat divided. Calyptra subcarnose, its border variously divided. Capsule round, dividing into four equal obtuse valves. Seeds numerous, very minute, adhering by very slender elastic filaments to the base and centre of the capsule.

Supposed anthers various in form, somewhat carnose, scattered over the surface of a distinct frond.

Only one species of it is known, P. Fabroniana (J. epiphylla.)

These characters are rather long, when considered merely as discriminative; and it is evident that they must have included many more circumstances, had they been intended as natural. It does not appear that brevity had been considered of much consequence in the construction of them, for in some instances, circumstances in common to all the Jungermanniae are mentioned under one genus, and not again repeated. What is said of the fruitstalk in the character of the first genus is quite out of place, and, if stated at all, it should have occurred in preliminary remarks on the fructification of Jungermanniae. When it is mentioned under the Raddian genus Jungermannia, that "the capsule is covered by the calyptra while it remains in the calyx," the statement almost necessarily leads to a mistake in regard to all the other genera, as we are nowhere informed that this character is in common to the whole of them. Since, in all the genera, the calyptra is stated to be "of one piece, its border variously divided," it was plainly unnecessary to state this at all; and it is worse than useless to say, under the new genus Jungermannia, that the calyptra supports the style; for if this be true of one of the new genera, it is true of all. It were easy, in several instances, to have shortened considerably the characters taken from the calyx; and we very much suspect that the attachment of the seeds to the spiral filaments, which is given as a character in several genera, is altogether hypothetical. The discovery of the fruit of J. laevigata (Bellincinia montana) is interesting: but we regret that the character which has been given of the fructification is too vague to throw any light on the question, whether this is not merely a variety of J. platyphylla (Antoiria vulgaris.) In this latter species, which is of very common occurrence, the mouth of the calyx may be subject to vary a little; but certainly to find it "truncate, inciso-serrate. (or irregularly torn,) with a deep notch on one side," as described by Dr. Hooker, is extremely easy; while we have neither seen nor heard of any specimen of it in this country with entire rounded lips. Supposing this arrangement to be followed, we think it would be indispensable that these two genera be united. We are at a loss to conceive why the insertion of the spiral filaments has not been mentioned under Frullania,—in both the species, of which it is very obvious, as well as in the genera towards the end of the arrangement; and we cannot think it correct to describe the calyxes of its two species as similar in form, or to state that that of Frullania minor (J. Tamarisci) is tuberculated.

The species of Candollea seem to us to agree in scarce any character of the calyx, except in its being truncated, and the other characters taken from the fructification are nugatory. The "irregular subcarnose vesicles," which are stated, after Hedwig, to be the anthers, are of a totally different nature, and seem to be merely the cellular structure of the leaf decomposing. The real anthers of this genus are always axillary. The species of this genus are also very discordant in habit. In short, we do not see that Candollea could be retained on any principle whatever. The character of the new genus Jungermannia seems to us to depend entirely upon the anthers, at least we can make nothing of what is stated respecting the female fructification: and it unfortunately happens, that our author had not seen the true anthers in any one of the species of this new genus, but had mistaken buds or vesicles for them—as the anthers, where they are known, are, in all the species referred by Raddi to Jungermannia, invariably axillary. The species referred to this new genus differ very much in the mouth of the calyx, and not more in fructification than in habit. The irregular division of the capsule in J. pusilla (Fossombronia angulosa) is very striking; and we take Fossombronia and Calypogeja to be by far the best characterized and most natural of his genera of leafy Jungermannia. The name Calypogeja, however, (καλυξ ὑπο γαιας,) is founded on an imperfect knowledge of the genus; and that part of the character which states that the calyx "is concealed vertically in the earth" should be taken out, as J. saccata of New Zealand, unquestionably a calypogeja, which has the pendent calyx on the summit of upright branches, never has it buried in the earth.

We deem it unnecessary to follow our author through his three frondose genera. To the arrangement we think it but just to give the praise of considerable ingenuity; but it certainly appears to us to be utterly unfit for the purposes of discrimination, and to give little or no information respecting the natural affinities of species; and hence to have no chance of being followed. We observe that there is no allusion to Dr. Hooker's monograph in the paper. We hope that it has subsequently fallen into the author's hands, and doubt not that it will assist him much in the study of this genus.

Jungermannia we take to be, like Erica, Solanum, and several others, an extensive vegetable type, unsusceptible, at least in the present state of our knowledge, of subdivision into genera; but of which the species, when arranged under well devised sections, like those of Mr. Dryander for Erica, or of Dr. Hooker for Jungermanniæ, are perhaps as easily mastered, as if each of these established genera were subdivided into twenty new ones, with unexceptionable generic characters, or characters that are exceptionable only on account of the minuteness of the parts from which they were taken, their being discoverable perhaps only upon very minute dissection, and the consequent difficulty of investigation. It would of course be quite useless to compare such an array of sections with generic characters of an inferior description.

We would earnestly recommend to all who attempt to make arrangements in systematic botany, that they commence with a minute investigation of all the parts, certainly at least of all the parts most important, with regard to classification, of all the species to be included in the arrangement, or at least of as many of the species as may be accessible to them. By no other means do we conceive it possible, that a new arrangement of plants that have been long known, which could serve any practical purpose, could be formed.

Consult Dillenii *Historia Muscorum*, 4to. Oxon. 1741, or the Edinburgh reprint. Micheli, *Nova Genera Plantarum*, fol. Flor. 1723. Hedwig, *Fundumentum Historiæ Naturalis Muscorum Frondosorum*, 4to. Lips. 1782. *Ejusd. Theoria Generationis et Fructificationis Plantarum Cryptogamicarum Linnæi*. 2d ed. 4to. Lips. 1798. *Ejusd. Species Muscorum*, 4to. Lips. 1801. Bridel, *Muscologia Recentiorum*, 4 vols. 4to. 1797—1819. Sir J. E Smith, in *English Botany*, 36 vols. 8vo. various years; in *Flora Britannica*, 3 vols. 8vo. 1800—1802; in Rees' *Encyclopædia*, under different titles. Sprengel's *Introduction to the Study of Cryptogamous Plants*, 8vo. De Candolle in *Flore Française*, 2d edit. 6 vols. 8vo. Hooker and Taylor's *Muscologia Britannica*. 8vo. 1818. Hooker's *Musci Exotici*. 2 vols. 4to. do. Monograph of the British Jungermanniæ, 1 vol. 4to. do. In *Flora Londinensis*, 2d series, fol. do. On Tayloria splachnoides in Brande's *Journal*, vol. 2d. Various papers in the *Linnæan Transactions*, and in various French and other foreign journals.

DESCRIPTION OF PLATES.

MUSCI FOLIOSI.

PLATE CCCCI.

Transverse Sections of Stems—viewed microscopically.

Fig. 1. Bryum ligulatum.
2. Hypnum dendroides.
3. Polytrichum commune.
4. Hypnum alopecurum.
5. Sphagnum obtusifolium.

Microscopic views, illustrative of the Structure of Leaves.

6. Hookeria lucens.
7. Hypnum denticulatum.
8. Sphagnum obtusifolium.
9. squarrosum.
10. cuspidatum.
11. Neckera crispa
12. Dicranum glaucum.
13 Diphyscium foliosum.
14, 15. Hookeria Lucens, with Roots springing from the Disk of the Leaf.

Figures, somewhat enlarged, illustrative of the different forms of the leaves; the absence or presence, and length, &c. of the Nerve.

16. Dicranum glaucum.
17. Hypnum scorpioides.
18. purum.
19. Schreberi.
20. medium.
21. Dicranum latifolium.
22. Diphyscium foliosum; *a*, the Stem leaf, *b*, the exterior Perichætial, *c*, the interior Perichætial leaf.
23. Tortula cuneifolia
24. Dicranum longifolium.
25. adiantoides.
26. Bryum punctatum.
27. ligulatum.

Microscopic drawings illustrative of the Flowers and germination of Mosses.

28. The Female Flower of Stypnum Triquetrum, with the Perichætial leaves removed.
29. Pistil of Hypnum triquetrum, exhibiting several little ducts in the Style.
30. Flower of Bryum Trichoides.
31. Male Flower of Bryum Androginum, *b*. a single anther.
32. Anther with the lid open.
33. Club-shaped succulent Threads of
a. An old and decayed anther.
34. Male Flowers of Dicranum bryoides, in the duplicatures of the Leaves.
35. A single Male Flower, with its envelopes.
36. Female Flower of Dicranum bryoides, in the base of the terminal Leaf.

PLATE CCCCII.

Fig. 1. Male Flower of Encalypta ciliata, with its perigonial Leaves.
2. Pistil of a Sphagnum, solitary in a Flower.
3. Plants in different stages of Germination, of Gymnostomum pyriforme.

Open Capsules, somewhat enlarged, showing the Structure of the Peristome, or its Absence.

4. Andræa rupertris.
5. Sphagnum obtusifolium.
6. Phascum subulatum.
7. Gymnostomum pyriforme.
8. Diphyscium foliosum.
9. Tetraphis ovata.
10. Octoblepharum serratum.
11. Splachnum vasculosum.
12. Grimmia apocarpa—with 3 teeth separate.
13. Tortula subulata.
14. Dicranum Scoparium, and 3 teeth separate.
15. Didymodon flexifolium, with do.
16. Funaria hygrometrica, three teeth of the Outer, and three of the Inner fringe seen.
17. Orthotrichum affine.
18. Hypnum medium—three teeth, and three cilia separate.
19. Tayloria Splachnoides *a*. Capsule, natural size, and *b*. enlarged. *c*. Calyptra, and *d*. four Teeth of the Peristome.
20. Dawsonia polytrichoides—*a* Capsule natural size, with the Calyptra—*b*. Inner Calyptra—*c*. Operculum—*d*. Capsule, somewhat enlarged, without the Operculum—*e*. Capsule cut open, to show the Columella and cilia issuing from it.
21. Lyellia crispa. *a*. Capsule, natural size, without the operculum. *b*. Ditto magnified. *c*. Vertical section of ditto to show the Columella, the substance of the Peristome, the interior Membrane, and the adherence of a part of the Peristome with the Columella *d* Calyptra magnified. *e*. Mouth of the Capsule, the central part of the Membrane drawn down by the shrinking of the Columella.
22. Pterigonium Smithii. *a*. Branch magnified. *b*. Capsule magnified. *c*. Calyptra magnified. *d*. Teeth magnified. *e*. Female Flower; the succulent Threads very unequal in length and thickness, the longer and thicker appearing to have an internal Tube.
23. Buxbaumia aphylla *a* Tuft of young Plants. *b*. Plants farther advanced. *c*. Capsule magnified with the Apophysis and a small part of the rough Fruitstalk *d*. Operculum separate. *e*. Vertical section of an immature Capsule, showing the distance between the outer and inner Walls; the connection between them by delicate succulent Threads; the singular flexure of the Columella in passing from the inner Wall of the Capsule to the Apophysis, and its incrassation in the Apophysis. *f*. Section of the Bulb, showing it to be hollow towards the lower end, and the curious division of the primary Root. *g*. Horizontal section of the Fruitstalk. *h*. Cellules greatly magnified.

PLATE CCCCIII.

Fig. 1. *i*. Base of the Fruitstalk, with a young Pistil rising from the same Bulb *k*. Reticulated Leaf, terminating in conferva-like filaments; *l*. Leaf composed entirely of conferva-like filaments. Both these leaves, the former of which we saw, were discovered by Mr. R. K. Greville when drawing these Figures. The leaves described in the *Edinburgh Philosophical Journal*, vol. ii. No 4 p. 377, were palmate, or much laciniate, with reticulations like those of the leaf *k*.

MUSCI HEPATICI.

2 Calyx of Jungermannia obtusifolia.
3 Do laid open.
4 Female Fructification of J. Hookeri, which has no Calyx.
5 Germen and abortive Pistilla of a Female Plant of do.
6 Anthers of do.
7 A single Anther of J. Hookeri magnified.
8 Perigonial Leaf of do.

9 Perigonial Leaf and Anther of J. platyphylla.
10 Calyptra and Capsule of do.
11 Calyptra, with the young Capsule enclosed, of J. resupinata.
12 Open Capsule of J. furcata.
13 Spiral Filaments and Seeds of do.
14 Leaves of J. asplenioides.
15 Leaf of J. juniperina.
16 J. setacea.
17 J. resupinata.
18 J. complanata.
19 J. nemorosa.
20 J. Hutchinsiæ.
21 J. dilatata.
22 Wart-shaped Receptacle, containing the Anthers of Marchantia conica.
23 Vertical section through the middle of a part of the Receptacle, showing the Anthers.
24 Under side of the Receptacle of the Female Flowers, showing the Pistilla, the Style reflected.
25 A single Flower separated from the Receptacle, and seen on the side by which it was attached.
26 A mature Capsule, open, with the valves revolute, exhibiting numerous spiral Filaments and Seeds.
27 A single spiral Filament, and a single Seed.
28 Plant of Riccia glauca, natural size.
29 Part of the Frond magnified, with Anthers appearing towards its Apex.
30 A Capsule nearly mature, with the Style.
31 Two mature Seeds.*

MUSIC.

1. Music is one of the fine arts, whose object is to give pleasure by the proper succession and combination of sounds. The word is derived from the Greek ΜΟΥΣΑ, *Musa*. In modern times music consists of two principal branches—*Melody*, or the proper succession of single sounds; and *Harmony*, or the proper combination of simultaneous sounds. These two united form Music: The former, indeed, may perhaps subsist independently of the latter; but harmony cannot well exist without the melodious arrangement of each of the several parts of which it is composed.

History.

2. Music is probably nearly coeval with our race, or, at least, with the first attempts to preserve the memory of transactions. Before the invention of writing, the history of remarkable events was committed to memory, and handed down by oral tradition. The knowledge of laws, and of useful arts, was preserved in the same way. Rhythm and song were probably soon found important helps to the memory; and thus the muses became the early instructors of mankind. Nor was it long, we may conjecture, before dancing and song united, contributed to festivity, or to the solemnities of religion.

3. The first instruments of music were probably of the pulsatile kind, and rhythm, it is likely, preceded the observation of those intervals of sound which are so pleasing to the ear. The first mention of stringed instruments, however, precedes the deluge. Tubal, the sixth descendant from Cain, was "the father of all such as handle the harp and the organ." About 550 years after the deluge, or 1800 before Christ, according to the Bible chronology, both vocal and instrumental music are spoken of as things in common use: "And Laban said, what has thou done that thou hast stolen away unawares to me, and carried away my daughters as captives taken with the sword? Wherefore didst thou flee away secretly, and steal away from me, and didst not tell me, that I might have sent thee away with mirth, and with songs, with tabret, and with harp?"

4. Egypt has been called the cradle of the arts and sciences, and there can be no doubt of the very early civilization of that country. To the Egyptian Mercury, or Thoth, who is called Trismegistos, or thrice illustrious, is ascribed the invention of the Lyre, which had at first only three strings. It would be idle to mention the various conjectures how these strings were tuned, or to try to settle the chronology of this invention. The single flute, which they called Photinx, is also ascribed to the Egyptians. Its shape was that of a horn, of which no doubt it was originally made. Before the invention of these instruments, as Dr. Burney justly observes, "Music could have been little more than metrical, as no other instruments except those of percussion were known. When the art was first discovered of refining and sustaining tones, the power of music over mankind was probably irresistible, from the agreeable surprise which soft and lengthened sounds must have occasioned." The same learned writer has given a drawing, made under his own eye, of an Egyptian musical instrument, represented on a very ancient obelisk at Rome, brought from Egypt by Augustus. This obelisk is supposed to have been erected at Heliopolis, by Sesostris, near four hundred years before the Trojan war. The most remarkable thing in this instrument is, that it is furnished with a neck, so that its two strings were capable of furnishing a great number of sounds. This is a contrivance which the Greeks, with all their ingenuity, never hit upon. "I have never been able," says the doctor, "to discover in any remains of Greek sculpture, an instrument furnished with a neck; and Father Montfaucon says, that in examining the representations of near five hundred ancient lyres, harps, and cytharas, he never met with one in which there was any contrivance for shortening the strings, during the time of performance, as by a neck and finger-board."

5. From the long residence of the Hebrews in Egypt, it is no improbable conjecture that their music was derived from that source. However that may be, music, vocal and instrumental, made one important part of their religious service. If the excellence of the music was conformable to the sublimity of the poetry which it accompanied, there would be no injustice in supposing it unspeakably superior to that of every other people.

6. The Greeks certainly received the rudiments of learning and of the arts from Egypt; but in the fine arts they excelled their masters and all others. Among the Egyptians, painting, statuary, and music became stationary, and were even fixed by the laws. Among the Greeks, on the contrary, the highest encouragements were continually held out to improvement, and

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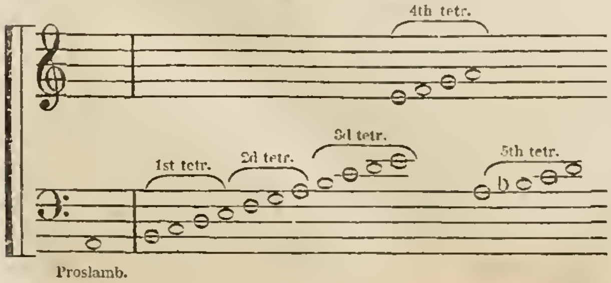
* We have been indebted for the above Article to the late Mr. John Stewart, Lecturer on Botany in Edinburgh, whose premature death, while he was correcting the last sheet of it, has been very deeply lamented. Mr. Stewart was on the eve of setting off for Chili, where he proposed to spend three or four years in examining the natural history of that interesting country. His profound knowledge of botany, the extent and accuracy of his general acquirements, and his ardent zeal for the promotion of science, fitted him, in a peculiar degree, for a scientific traveller, and excited among his friends high expectations, which he has not been permitted to realize. Ed.

that perfection was obtained which the admired remains of antiquity exhibit. It is not questioned that in architecture and statuary they produced models which the moderns hardly hope to equal. Music among them was always of capital importance in their religious rites, their processions, their games, and their theatrical representations. The same honours and rewards were held out to excellence in this as in the sister arts. The same contests excited emulation among candidates for fame and wealth. Hence music may well be supposed to have been carried to the same perfection as the other fine arts; and should we give implicit credit to the assertions of the learned, this was the case. But when we come to particulars, we do not find these expectations justified. On the contrary, every candid and qualified judge will find abundant reason to conclude, that they stopt at a point of perfection far lower than what has been attained by the artists of modern Europe.

7. The diatonic scale, to which we have been accustomed from infancy, appears to us so simple and natural, that we should suppose it to have been one of the earliest discoveries in the science or art. This was, however, by no means the case. The first Grecian lyre, attributed to Mercury, had only four strings, which is believed to have been nearly the notes which the moderns call E, F, G, A, beginning on the third space of the bass. The additions of other strings to this lyre are ascribed to different musicians, Linus, Orpheus, Thamyras, who added strings corresponding to D, C, B, extending the scale downwards; which completed the heptachord, or scale of seven sounds, a compass, says Dr. Burney, which received no addition till after the time of Pindar, who calls the instrument then in use the *seven-tongued lyre.* According to Suidas, the Grecian lyre had only four strings from the time of Amphion till that of Terpander, a period of 856 years, who added the three strings which completed the heptachord, consisting of two *conjoint tetrachords.* About 150 years after this period, Pythagoras is said to have added or introduced an eighth string, which completed the octave from B to b; which then consisted of two *disjunct tetrachords.* It is to be observed that the interval of perfect fourth, which the Greeks call a tetrachord, was a favourite interval with them, and on the different ways of filling up this interval, depended their different *genera,* which we shall give some account of bye and bye. To the octachord of Pythagoras was afterwards added a graver string, corresponding to our A, on the first space in the bass. This string was called *proslambanomenos,* or added-string, and was the gravest sound of the Grecian scale.

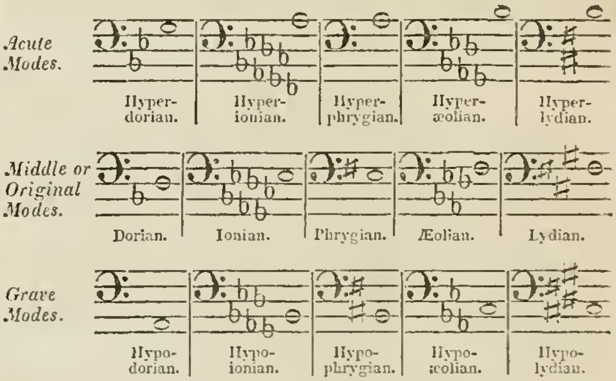
Subsequent additions to the acute part of the scale extended it to the double octave above *proslambanomenos.* This was called the great system, the perfect and immutable system.

8. This system they considered as composed of five *tetrachords,* with the note *proslambanomenos,* or added-note, which was not reckoned as part of the tetrachords. The system is exhibited in the following scale, in modern notation.



Each tetrachord ascending, proceeds by a semitone and two tones. The first and second tetrachords, as also the third and fourth, are conjoint, that is, the highest note of the former, is the lowest of the latter: the second and third tetrachords are disjoint, being separated by a tone. The fifth tetrachord began with the middle sound of the lyre or octave to *proslambanomenos,* so that it comprehended part of the second, and part of the third tetrachords, like the others, ascending by semitone and two tones. This tetrachord seems to have been formed for the sake of a perfect fourth, to the sixth of the scale.

9. Such was the diatonic scale of the Greeks at its gravest pitch, or in their gravest *mode.* But they used this scale at many different pitches, and these constituted their *modes,* which word, therefore, is analogous to our *keys.* Aristoxenus, the oldest writer on music, whose works have come down to us, and who was contemporary with Aristotle, admitted only thirteen modes, though subsequent musicians allowed of fifteen. There seem to have been originally five modes, the Dorian, Ionian, Phrygian, Æolian, and Lydian, rising above each other by semitones. To each of these belonged their relative modes, fourth above, and fourth below, expressed by the addition of hyper and hypo; as Hyperdorian, Hypodorian, &c. The scale above described, is the Hypodorian, which is generally allowed to have had its *proslambanomenos* of the pitch of our A, on the first space in the bass. The following table, therefore, shows the whole in their relations to each other.



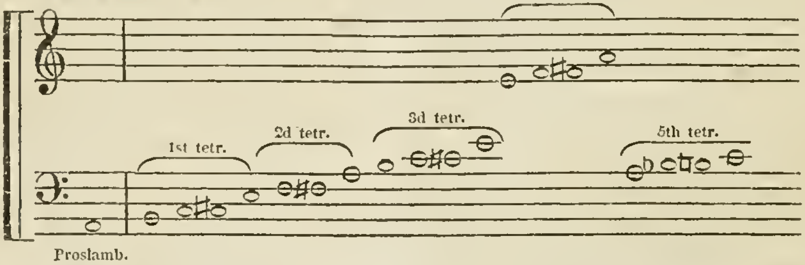
Aristoxenus refused admission to the Hyperæolian, and Hyperlydian, as being only octaves of the Hypoionian and Hypophrygian. For the same reason, he might have rejected the Hyperphrygian, being the octave of the Hypodorian. But these seem to have been admitted as completing the Phrygian, Æolian, and Lydian, by furnishing them with the relative modes in the fourth above. The names of these modes point out very clearly the connexion which the ancients, as the moderns do, felt to subsist between these related keys. Allowing two octaves to each of these modes, the whole compass of the fifteen, was three octaves and one tone, from A on the first space in the bass, to B over the first ledger line, above the staff in the treble. The ancients ascribed very different effects to these modes, insomuch that it is difficult to conceive these could have arisen from a mere transposition of the same intervals to a different pitch. Hence, it has been conjectured that some other character arising out of the rhythm, or the poetry to which the music was set, belonged to each mode. "I should suppose," says Dr. Burney, "that in times of musical refinement among the ancients, when the characteristics of national melody were somewhat effaced, the names of the musical modes had much the same use as our technical terms *grazioso, grave, allegro, con furia*, and that in lyric poetry, there were particular species of feet allotted to each mode. If that was the case, we might easily suppose that a change of mode would be a change of style and measure." This supposition has some countenance by the observation, " that Morley and all the old writers upon modern music, before the use of bars, affixed no other meaning to the *modes* or *moods*, as they were then called, than that of regulators of *time* or *measure*."

10. " It is remarkable," says Dr. Burney, " that all the ancient modes or keys were *minor*, which must have given a melancholy cast to their melody in general; and however strange this may appear, it is as certain as any point concerning ancient music can be, that no provision was made for a major key in any of the ancient treatises or systems that are come down to us." But the truth is, that no comparison can well be made between ancient music and the modern *modes*, whether major or minor. The characteristic distinctions of these modern modes arise out of the thirds and sixths of the scales major and minor; and of true consonant thirds and sixths, the ancients had no knowledge for many ages, comprehending the most splendid periods of their history. They admitted no other concords but fourths, fifths, and octaves, which being always tuned perfect, their diatonic tetrachord was divided into two major tones and a small interval usually called a semitone, but which Euclid demonstrated to be much smaller. The thirds were therefore all so false, that it is no wonder they ranked them among the discords. Their melodies consequently were built on principles very different from ours. The diatonic scale of the ancient Greeks, indeed, is to our ears so untuned, that it is extremely difficult to fancy that any tolerable melody could be drawn from it. Harmony, in the modern sense of the word, is altogether out of the question.*

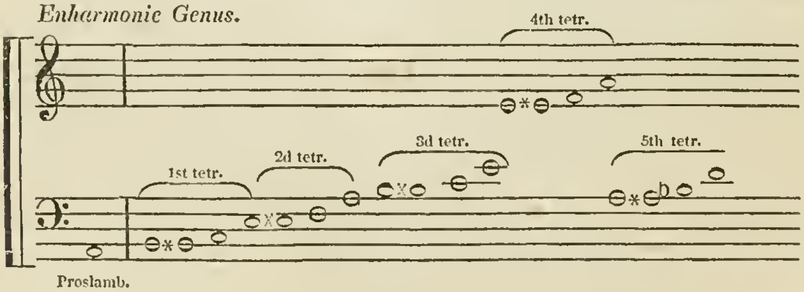
11. Didymus, an eminent musician of Alexandria, who was cotemporary with the Roman emperor Nero, was the first who described the true major third, consisting of a major and a minor tone; the major or diatonic semitone, which results from subtracting this major third from the perfect fourth; and the minor third, consisting of major tone and major semitone; yet his arrangement of the intervals was not that which is found best for the purposes of modern harmony. Ptolemy, the celebrated astronomer and geometer, who flourished about 150 years after the Christian era, among many other arrangements of the scale, first proposed what is our modern diatonic, which he calls Diatonicum Intensum: so long was it ere our simplest scale of musical notes was invented.

12. If the ancient diatonic genus, at least as described by theorists, appears so strange to us, their other genera are still less intelligible. It has already been observed that their different genera arose out of the different ways in which they divided their favourite interval, the perfect fourth. In the diatonic genus, as already described, the scale ascended by a semitone and two tones. The chromatic ascended by two semitones and minor-third. The enharmonic by two quarter tones and a major-third. The extreme sounds of the five tetrachords remained as in the diatonic genus. The scales filled up with their peculiar intervals were these.

Chromatic Genus.



Enharmonic Genus.



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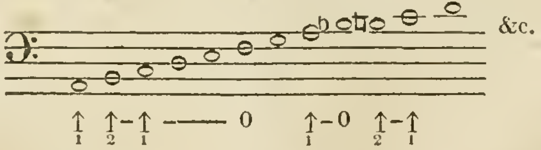
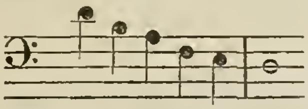
* The diatonic scale of the ancients is heard on Mr. Liston's Enharmonic organ, by using the pedals thus:



The effect of this scale is so disagreeable to our ears as to give no very favourable notion of ancient music. Possibly in practice the harshness of the thirds was diminished by some such *temperament* of the perfect concords, as the moderns are constrained to admit, in keyed instruments in general. It is easier, as Dr. Smith observes, for practical musicians to follow the judgment of the ear, which leads naturally to an occasional temperament of any disagreeable concords, than to learn and put in practice the theories of philosophers. That in practice they did so temper the perfect intervals, is the opinion of Salinas, which he endeavours to prove by a quotation from Galen, which, however, does not bear him out. See Smith's *Harmonics*, Art. 12.

The mark X like St. Andrew's cross, denotes the elevation of the note before which it is set, a quarter-tone, dividing the semitone into two intervals, equal or nearly equal. This character is adopted in modern notation to denote the elevation of a sharpened note by another chromatic semitone, and is called double sharp. Each of the three genera was subdivided into different species, but we shall not trouble the reader with the conjectures of learned men respecting them. "The distinctions of the genera," says Dr. Burney, "seem to have been long religiously observed in Greece: as the lyre was allowed but four strings to each tetrachord, and flutes were bored in a particular manner for each genus, in which no provision was made for producing the tones peculiar to the other two." The invention of the enharmonic genus is ascribed to Olympus the Mysian, the scholar of the unfortunate Marsyas, who disputed with Apollo. Dr. Burney, from a passage in Plutarch's Dialogue concerning music, has drawn a very ingenious conjecture respecting the enharmonic of Olympus. It seems to have consisted merely in the omission of certain notes in the diatonic tetrachords. The quarter tones of the enharmonic he supposes to have been a refinement of later times. "It must be remembered," he observes, "that the Dorian mode in which Olympus is said to have composed his melodies, answers to our key of D minor. Now in the tetrachords of this mode, if we omit every third sound, we shall have the following melody.



Proslamb. only wanting to complete the octave.

Now this is exactly the old Scots scale in the minor key, a circumstance which must strike every one who reads the passage of Plutarch, that is at all acquainted with the intervals of the Greek scale, and with Scots music." For the passage itself, and for the reasoning with which he supports this conjecture, we must refer our readers to his Dissertation on the music of the ancients, prefixed to the first volume of his History of Music. We shall only add, that, granting all that the Doctor supposes of the similarity of the scales, it does not follow that the celebrated *Nomes*, or airs of Olympus, bore any great resemblance to the old Scottish airs. The rhythm of the former, which most probably was hexameter, must have given them a totally different character. Besides, the old Scottish airs, though drawn from a defective scale, and carefully avoiding the major seventh of the scale, at least in the minor mode, do yet in their closes plainly point at cadences in the harmony to which they belong, a thing of which, there is every reason to believe, the ancients had no knowledge.

13. The music of the ancients was entirely vocal, and entirely regulated by the rhythm of the poetry; even their instrumental music was only vocal music played on instruments, insomuch that they had no notation for time. The poet and musician were long united in the same person. The hexameters of Homer were sung possibly to the same melody or recitative, which he himself composed. The lyric poets, Alcaeus, Sappho, Anacreon, literally sung their poems to the lyre. Pindar, it is well known, set his own poems to music, and sung them himself in the public contests; and his skill in music, and the excellence of his voice, contributed their share to his victories. The entire subjection of the music to the quantity of the syllables, must have made it resemble our recitatives rather than our airs, even in those verses which were composed of feet of equal quantities, such as hexameters, and pure iambics, and trochaics. But the continual change from common to triple time, as we should express it, in their lyric versification, is a thing of such a nature, that it is extremely difficult for a modern musician to conceive that music, subjected to such measures, could be tolerable. That habit had formed their ears to find pleasure in such music, is not to be doubted; that it is not quite fair to try their taste by modern standards, we allow; but to give up our rhythm, and to return to that of the ancients, as learned men have contended we ought to do, would be returning to acorns after having enjoyed the gifts of Ceres. "Let the most inventive composer," says Dr. Burney, "try to set half a dozen hexameters, pure iambics, or any other verses that will fall into regular common, or triple time, and he will soon find that no resources of melody are sufficient to disguise or palliate the insipid and tiresome uniformity of the measure; and as to any thing like expression, we may as well expect to be affected by the mechanical strut of a soldier on the parade. In other metres, where feet of different kinds are intermixed, *some* variety is indeed acquired, but it is a misplaced variety, which, without obviating the tiresome effect of a confinement to no more than two lengths of notes, adds to it that of an awkward and uncouth arrangement; the ear is still fatigued with uniformity where it requires change, and distracted by change where it requires uniformity. Modern music, on the contrary, by its division into *equal* bars, (measures) and its *unequal* subdivision of these bars by notes of various lengths, unites to the pleasure which the ear is by nature formed to receive from a regular and even measure, all the variety and expression which the ancients seem to have aimed at by sudden and convulsive changes of time, and a continual conflict of jarring and irreconcilable *rhythms*."

14. It is very surprising that so ingenious a people as the Greeks should have rested contented with so imperfect and so cumbrous a notation as theirs was. It was made up of the letters of the alphabet, which were not sufficiently numerous for their purposes; they were therefore inverted and placed in various positions, mutilated and combined. No analogy drawn from the octave or the tetrachord, from their genera or modes, is discoverable in these characters. Hence they amounted to 1620 different notes, and all this without any notation of time. The same sounds were differently noted for the voice and for instruments; and the difficulty of learning to read music was excessive.

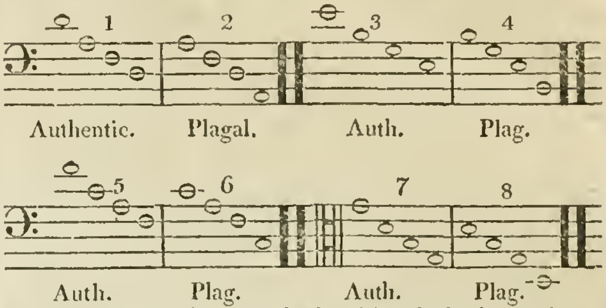
15. It has been a matter much debated among the learned, whether the ancients were possessed of harmony, in the modern sense of the word—that is, of music in parts. For a full and very candid account of the controversy, we refer the reader to Dr. Burney's dissertation on the music of the ancients, prefixed to the 1st vol. of his History. The account already given of the scale of the Greeks, art. 10. shows that it could not furnish any sufferable combinations, but fourths, fifths, and octaves; and the conclusion to which the most learned and unprejudiced inquirers have come, Meibomius, Dr. Wallis, M. Burette, Padre Martini, &c. is, that the ancients were ignorant of counterpoint, or music in parts.

16. In the general wreck of literature and the arts which followed the irruption of the barbarous nations into the western empire, music found an asylum in the church. It was there that some knowledge of ancient music was preserved; and that new inventions originated, which, in process of time refined and perfected, became the modern system of harmony. The practice of singing psalms and spiritual songs is recommended by the Apostles, both by

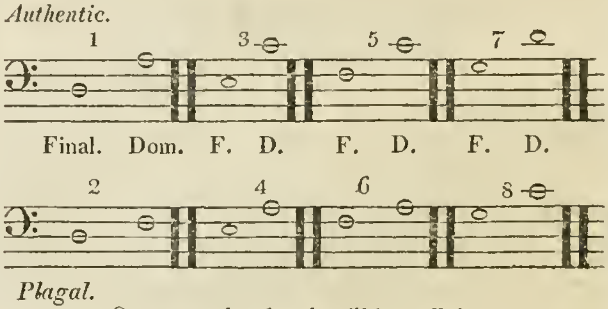
precept and example; and, there can be no doubt, was adopted in the meetings of the first Christians for social worship, and for mutual encouragement, comfort, and edification. It is reasonable to suppose that this music was taken at first, rather from the sacred songs of the Hebrews than from the temple worship of the heathens. When afterwards the church began to imitate the splendour of the Pagan worship, and adopted their images and processions, we may believe she would adopt their music also. Of this indeed, as Dr. Burney observes, the versification of the hymns received into the service of the church, affords an indisputable proof, as it by no means resembles that of the psalms or any other Hebrew poetry. Examples may be found in all the breviaries, missals, and antiphonaries, ancient and modern, of every form of versification practised by the Greek and Roman lyric poets. Prudentius, a Christian poet, who died toward the end of the fourth century, was author of most of the hymns in the Roman breviary. About the middle of the fourth century, Flavianus, bishop of Antioch, established a regular choir in his church, which he divided into two parts, and made them sing the psalms of David alternately. This practice, says Theodoret, which began at Antioch, afterwards spread itself to the end of the world. This is called *Antiphonal* singing, and out of it afterwards grew harmony in fugue.

17. Ambrose, bishop of Milan, introduced this practice into the western church, towards the end of the fourth century. He also chose four *modes,* in which he appointed the service of his church to be sung. To these modes the old Greek names of Dorian, Phrygian, Æolian, and Myxolydian were given; but the Grecian modes were really the same scale in different keys, whereas the Ambrosian are merely the same series of sounds as they lie in one scale, reckoned successively from D, E, F, and G. These four modes are called Authentic. To each of these Pope Gregory the Great, about 230 years after, in the beginning of the seventh century, added what was called its *plagal,* that is, according to the most probable derivation, its adjunct or collateral mode. Each of these had the same final or key note as its relative authentic, from which there is no other difference than that the melodies in the four authentic or principal modes are generally confined within the eight notes above the key-note, and those of the four plagal or relative modes within the compass of the eight notes below the fifth of the key. "If the chant," says Rousseau, "descends three degrees below the tonic or key note, then the tone (or mode) is plagal." These are called the eight ecclesiastical tones or modes. The following examples, which are taken from Dr. Burney, but given in a notation more familiar to our readers, exhibit the essential features of each.

Essential Sounds of the Tones, or Ecclesiastical Modes.

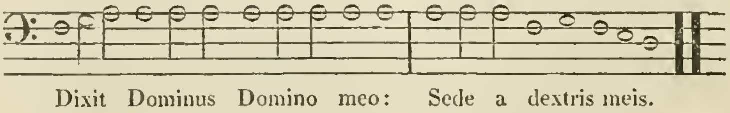


Each tone, besides its final, with which the psalm or chant generally begins, but always ends, has another essential note, called its *dominant,* which prevails chiefly in the song; and this makes another distinction between the authentic and plagal modes. Here is a table of the finals and dominants of the tones.

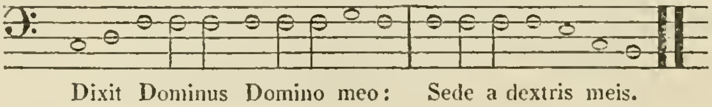


One example of each will be sufficient:

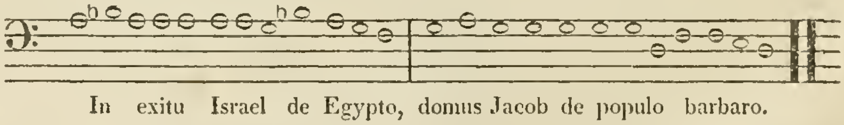
Authentic.



Plagal.



Irregular.

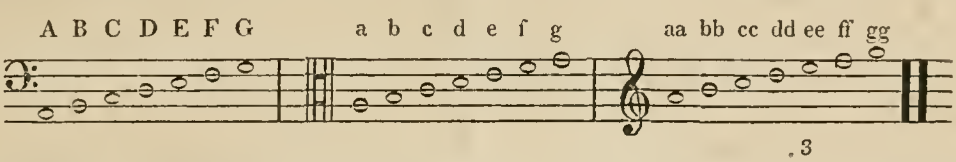


The only accident allowable in the Ecclesiastical modes is a flat to B, which is removed by a ♮. No character ♯ occurs in genuine chants of high antiquity. Hence the bald conclusion of the second of these examples, like what we still hear in the Psalmody in country churches. The third of these examples is called irregular, because it does not appear to belong to any of the modes.

18. Gregory is said to have banished from the church rhythmic singing, as too gay and paganish, and to have established the plain chant, or *canto fermo,* in which the notes were all of equal length, as in our psalmody, or at least of no stated measure, as in Cathedral chanting. Rousseau says, that "the Christians began to have churches, and to sing psalms and other hymns, at a time when music

had already lost almost all its energy; that they deprived it of the greatest power which remained to it, namely, that of rhythm and metre, when from the verse to which it had always been applied, they transferred it to the prose of the sacred books, or to some kind of barbarous poesy, worse for music than prose itself. Then one of the constituent parts of music vanished, and the chant drawling uniformly, and without any kind of measure, in notes of nearly equal length, lost with its rhythmic and cadenced march, all its energy." Now, though there can be no question that the energy of music depends greatly on rhythm and cadence, yet we cannot help thinking that in the end she gained by laying aside the ancient lyric measures, and that the canto fermo of the church made way for that better and more energetic rhythm of her own, which, after the invention of the time table, she acquired on the stage, and in the chamber.

19. Pope Gregory conferred a great benefit on music, by applying the same Roman letters to denote all the replicates of the same sound in different octaves. Before his time, it appears, the sounds in the double octave, or great system of the Greeks, had been denoted by fifteen Roman letters. Gregory reduced them to seven, applying the same letters, in different forms, to three different octaves, as in the following scale.



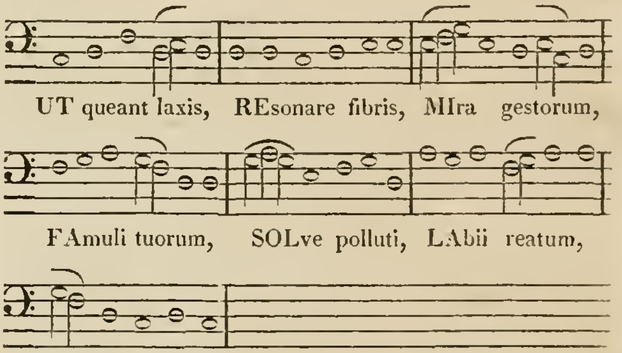
This was an important step in notation. These seven letters are still used throughout Europe, as the denominations of the sounds of the Diatonic scale: and we see from the predilection of the ancients for the minor scale, how the first letter of the Alphabet comes to occupy its present place, instead of denoting the fundamental sound of the major mode.

20. From this period forwards may be traced several steps in the method of notation. First, Gregory's letters were written over the syllables to which they were to be sung, thus:

dc b c de d c b a b d a $\overset{\frown}{\text{GF}}$
Sit nomen Domini benedictum in sæcula.

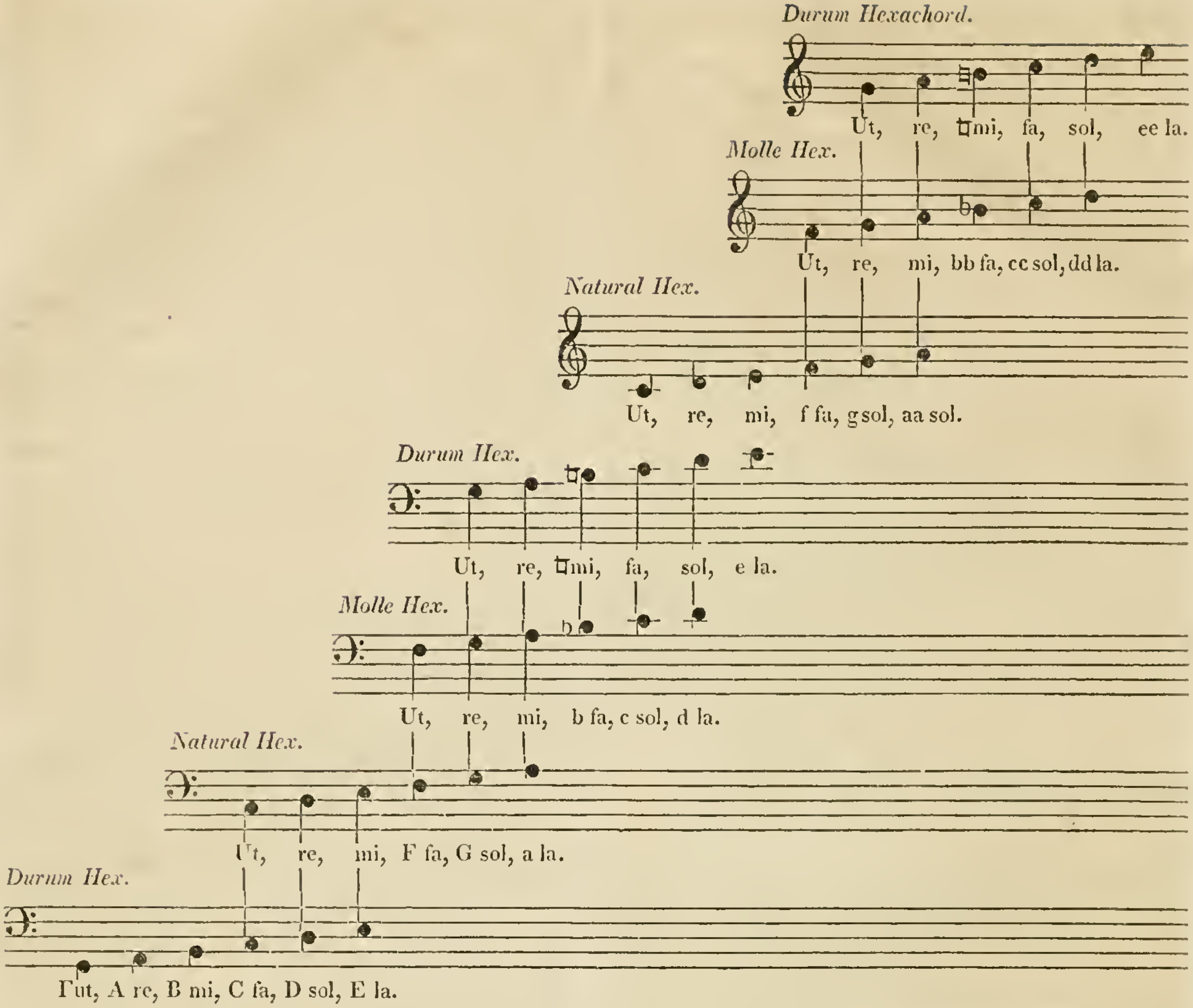
Afterwards the letters were placed higher or lower in the page, according to their place in the scale, seemingly to assist the imagination in reading the notes. Then the alphabetic characters were placed at the beginning of the lines in which the words were written, of which curious specimens may be seen in Dr. Burney, vol. ii. pp. 33, 35, &c.; and in Sir John Hawkins, vol. i. p. 454. A little before the time of Guido, *points* were placed on seven lines, perhaps in imitation of the strings of the lyre. At last Guido placed the *points* or notes on both lines and spaces, and thus he reduced the number of lines to four, which is the staff still used in the canto fermo of the Roman church. One letter placed on a line at the beginning of the staff, determined the names of the notes on the other lines, and in the spaces. Hence the origin of the *clefs*, which are nothing but Gothic letters disfigured.

21. Guido was also the inventor of the method of *solmisation*, or singing by syllables, which are so used as to mark the places of the semitones. He was led to this invention by observing that in a hymn to St. John, the first and middle syllables of the three first lines formed a regular ascent in the scale of the major mode, as we should say. This hymn is preserved, and, as connected with an invention which is still in practice in most countries of Europe, we consider it a curiosity worthy of being presented to our readers.


UT queant laxis, REsonare fibris, MIra gestorum,
FAmuli tuorum, SOLve polluti, LAbii reatum,

Sancte Johannes.

The Greeks used four syllables, Ta, Te, The, Tho, with which they practised in learning to sing their tetrachords, so that the idea of always applying the same syllable to a sound, similarly related to the rest of the scale, was not original. But it may seem surprising that Guido stopped short of Gregory's seven letters, which completed the scale, the eighth being a repetition of the first. In this Guido made a retrograde step to the system of the Greeks, among whom the tritone from the fourth to the seventh of our major scale was carefully avoided. Like them, Guido and his followers regarded the greater seventh of the scale, so important in our modulations, as irregular, or not belonging to the system. He distinguished three Hexachords, which being repeated in the higher octaves, carried the scale from G on the first line of the bass, to ee on the fourth space of the treble, as exhibited in the following Diagram.


Durum Hexachord.
Ut, re, ♮mi, fa, sol, ee la.
Molle Hex.
Ut, re, mi, bb fa, cc sol, dd la.
Natural Hex.
Ut, re, mi, f fa, g sol, aa sol.
Durum Hex.
Ut, re, ♮mi, fa, sol, e la.
Molle Hex.
Ut, re, mi, b fa, c sol, d la.
Natural Hex.
Ut, re, mi, F fa, G sol, a la.
Durum Hex.
Γut, A re, B mi, C fa, D sol, E la.

22. These three hexachords are exactly similar. The reason of the different names assigned them, is thus stated by Dr. Burney. "In the *Canto fermo*, or ancient chants of the Roman church, F was not allowed to be made sharp in the key of G, which rendered the B as tritonus to F ♮ *harsh* and *difficult;* hence the hexachord of G was called *durum;* that of C, in which the B flat was unnecessary, *naturale;* and that of F, on which the B flat was indispensable, *molle*, soft; as it removed the harshness which the tritonus or sharp fourth, consisting of three whole tones between F and B natural, would have occasioned." Our characters, ♮ natural, and ♭ flat, are derived from these distinctions: The natural or durum B, was written with a square or Gothic letter; and the soft or flat B, with a round or Roman letter. The French to this day call the ♮ *B quarre*, and the ♭ *Bemol.* We here see also the origin of the word *gammut.* The lowest note of Guido's scale being a tone lower than the lowest of the old scales, and being octave below Gregory's G, was denoted by the Greek letter Γ, gamma; and this sound having the syllable UT given it, was called *gamma ut*, and contracted to *gammut*, and used to signify the whole scale. By this diagram also, the reader may understand the names given by our forefathers to the different notes of the scale, which expressed their relations in different hexachords: As for instance, G, *sol, re, ut;* for this note is *sol*, in the hexachord of C, *re*, in that of F, and *ut* as the first sound in its own hexachord.

23. Guido, the author of these important inventions, which have rendered his name so celebrated in the history of music, was a monk of the order of St. Benedict, at Arezzo in Italy: hence he is called Guido Aretinus. He flourished in the beginning of the eleventh century. So great a change did these inventions make on the study of music, that as he himself says, the boys under his care were able to accomplish in three days, what they could not have done by any other method, in as many weeks. "By divine assistance," says he, "I have pointed out such a method of notation, that by a little help from a master at first, an intelligent and studious person may easily acquire the rest by himself. And if any one should suspect my veracity, let him come to our convent—let him make the experiment—let him examine the children under my care, and he will find, that though they are still severely punished for their ignorance of the Psalms, and their blunders in reading, they can now sing correctly, without a master, the chants to those Psalms of which they can scarce pronounce the words." Guido's merit was acknowledged in his own day. In the year 1022, Pope Benedict the VIII. sent for him to Rome, and treated him with great kindness. The successor of Benedict, John the XXth, also sent for him, and condescended to become

his scholar; and found by personal experience the truth of those reports which he could hardly believe.

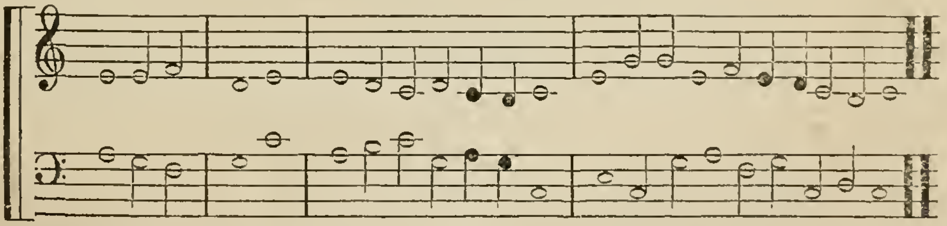
24. Guido's method of solmisation by hexachords, is to this day practised at Naples, where some of the greatest singers whom Europe has produced, have been formed. In England, since the beginning of the seventeenth century, it has been the general practice to use only four syllables, omitting *ut* and *re;* so that the octave is divided into two tetrachords as among the Greeks; the interval *mi, fa*, being always the semitone. In France and Italy a seventh syllable *si* has been added to Guido's syllables, in order to complete the diatonic scale; the Italians also have for *ut* substituted *do*, as more fit for singing; and this method in England has latterly prevailed over that by four syllables. The French have, however, entirely forsaken Guido's principles, by using the syllables not as denoting the diatonic scale, whatever may be the pitch of the key-note, but as fixed sounds. Thus they say of a piece of music, in the key of C, that it is in *Ut;* in D, that it is in *Re*, and so on; for which they are with justice severely censured by Rousseau. (*Dict. Mus. art. Solfier.*)

25. Guido has been very generally said to have invented *counter-point*, or the harmony of simultaneous sounds. The word *counterpoint*, which is derived from Guido's notation, in which sounds to be sung simultaneously were signified by points or notes placed opposite each other in the same staff, has probably given occasion to that general belief. The word counterpoint, however, was not even introduced till a succeeding age; and the practice of harmony, rude indeed, and such as would be even shocking to our ears, may be traced several ages before his time.

26. The invention of the organ, and its introduction into the service of the church, is an important era in musical history; for there can be no doubt that this noble instrument gave birth to music in consonance, and had a most material influence on the progress of that art towards perfection. The organ blown by bellows, is an improvement of the hydraulic organs of the ancients; but at what period, or by whom this improvement was made, is unknown. It is generally agreed, that organs were first introduced into the service of the church by Pope Vitalian, in the year 666. About the beginning of the ninth century, they had become pretty general over Europe. The organ, no doubt, was first used as a unison accompaniment to voices, but the facility which it furnishes of sounding several notes at once, would soon lead to the observation of the agreeable effect of some consonances. Octaves, fifths, and fourths, were the first intervals used in consonance; and the first accompaniments consisted of successions of those concords running parallel with the voice. When, in imitation of such accompaniments, these concords were given to voices, this was called *organizare*, and an accompaniment to the canto-fermo for the voice, was called *organum;* a clear proof of the true origin of the practice. In an ancient manuscript, written by John Cotton, nearly about the time of Guido, the words *diaphonia* and *organum* are used as synonymous. "This kind of singing," says he, "is commonly termed *organum*, because the human voice *sounding double* notes, resembles the effect produced by the instrument which is called an *organ*."

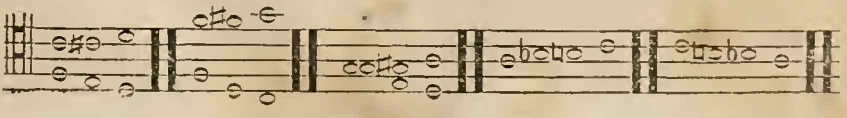
27. Hubald, a monk of St. Amand in Flanders, who flourished in the age preceding that of Guido, was the author of a treatise on music, out of which Dr. Burney has given specimens of the crude harmony of those days, consisting entirely of fourths or fifths. He has, however, one idea, "that while one voice remains on the same tone, the other may wander about at its pleasure," which, as Dr. Burney says, shows him to have been a man of genius and enlarged views, who could penetrate beyond the miserable practice of his time into our *organ points*, and multifarious harmony upon a holding note, and suggest the *principle*, at least, of the boldest modern harmony. It does not appear that Guido made any great improvements in the art of counterpoint, or *organizing* as he calls it. The fourth is still the favourite interval; thirds are sparingly admitted; and what is very singular, he rejects, and even forbids the use of the fifth.

28. Franco of Cologne, who flourished about the middle of the eleventh century, made considerable advances in the art, which he is the first to call *discant*. He divides concords into three classes, *perfect, imperfect*, and *mean*. The perfect are unison and octave, the imperfect are the thirds, and the mean are the fourth and fifth. The sixths, major and minor, he ranks among the discords, though he says they may be allowed in discant. The lesser second, greater fourth, and greater seventh, he says are perfect discords, and intolerable to the ear. He recommends the mixture of thirds, major and minor, with unisons and fifths. Dr. Burney gives the following specimen of his method of interweaving imperfect with perfect concords.



"Though this fragment," says he, "may neither please nor interest the modern contrapuntist, yet whoever compares it with the compositions of Hubald, Odo, and Guido, must regard it with wonder."

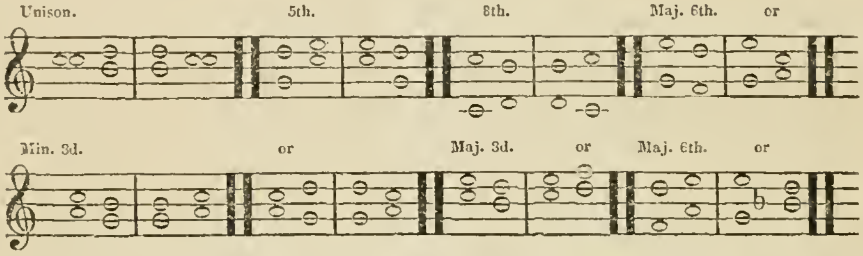
29. After Franco, music seems to have continued much in the same state, as far as regards harmony, for two centuries. Succeeding writers seem to have regarded him as their master. About the end of the thirteenth century, however, we find a commentator on Franco, more interesting than the rest, and who deserves to be ranked among the improvers of harmony, Marchetto of Padua; one of his treatises on music is dated 1274. This, however, must have been written at an early age, as there is another treatise of his dedicated to Robert, King of Naples, who reigned from 1309 to 1344. In his works are found the first examples of the use of the ※, and of chromatic modulations; as in the following examples, which clearly evince that the art had made very considerable advances.



Marchetto is the first who speaks of the resolution of discords, and lays it down as a rule that no two-sevenths, or fourths used as discords, should succeed each other; that after a discord, the part which has offended the ear should make it amends by becoming a concord, while the other stands still.

30. In the fourteenth century, flourished *John de Muris*, so called probably from the place of his birth at Meurs, in Normandy; to whom many inventions in music have been attributed. "His *Art of Counterpoint*," says Dr. Burney, "though comprised in a very few pages, is the most clear and useful tract on the subject which those times can boast." He begins by informing his reader that all beyond the octave is repetition. That "within the octave there are six species of concord, three perfect, and three imperfect; of the first kind are the unison, 8th, and 5th; and of the second the two 3ds, and major 6th. The first of the perfect," he says, "is the *unison*, which though by some not allowed to be a concord, yet, according to Boethius, is the source and origin of all consonance. The unison naturally requires after it a minor 3d; which, on the contrary, for variety, is best succeeded by a perfect concord. The 5th, being of the perfect kind, is well followed by a major 3d, and e *contra*. The octave, another perfect concord, may be succeeded by a major 6th; after which a perfect or imperfect concord may be taken. It is the same with the minor 3d, which being of the imperfect kind, may be succeeded either by a perfect or imperfect concord. The major 3d, though best followed by a 5th, yet may be succeeded by another 3d, but then it must be minor. The major 6th too, though best followed by an 8th, may yet be succeeded either by a perfect or imperfect concord of another species, for the sake of variety; it can be followed by a 5th only when the under part rises a major or minor 3d; but by 3ds and 6ths at pleasure. Every composition should begin and end on a perfect concord; and it must be remembered that no two parts should ascend or descend in *perfect concords*, though imperfect may be used without limitations; and, lastly, care must be taken that when the under part ascends, the upper should descend, and the contrary."

31. "Most of these rules," the Dr. continues, "were given by Franco, but with less clearness and precision; and as they will not only show that harmony had made some progress in the fourteenth century, but are such as would not shock modern ears, I shall present them to the musical reader in notes.



"The minor 6th, I know not why, is called a *discord* by Franco, and has no admission among concords by John de Muris; though it is only an inversion of the major 3d, which both allow to be a concord.

"John de Muris makes no mention of the 5th in this Tract, though in his *Speculum Musicæ*, he gives rules for discanting on a *succession of fourths* under the barbarous term *diatessaronare*.

"Prosdocimus de Beldemandis (in a Tract on Counterpoint, written 1412,) is the first who allows the minor 6th a place in the catalogue of concords, and is explicit in speaking of the 4th as a discord. However," he says, "it is less a discord than the 2d or 7th, and may be placed in a middle class *between* concords and discords."

33. The first compositions in harmony were in simple counterpoint, *i. e.* note against note. But even this required the chant to proceed with a uniform pace, and the relative length of the notes to be signified by a proper notation. Hence the invention of the time-table. This has been ascribed to John de Muris, and to Franco. It appears, however, to have arisen between the times of Guido and Franco, and to have made some progress before the latter extended and improved it, and gave it that form which it kept for several ages.

34. "Music, before the invention of *counterpoint*," says Dr. Burney, "consisted, as far as we are able to discover, in canto fermo, or melodies equally simple; on this inelegant and insipid treble, *harmony* was grafted, and practised in the church; but the discovery which was afterwards made in the invention of characters for time was much more important, as it constitutes the true era of musical independence; for, till then, if melody subsisted, it was entirely subservient to syllabic laws. Music, considered abstractly, without the assistance, or rather the shackles of speech, is now become a rich, expressive, and picturesque language in itself, having its (own) forms, proportions, contrasts, punctuations, members, phrases, and periods."

35. The work of Franco, entitled *Franconis Musica et Cantus Mensurabilis*, is inserted entire in the Collection which M. Gerbert, the Prince Abbot of St. Blaise, has published, under the title of *Scriptores Ecclesiastici, potissimum de Musica Sacra*. It contains an introduction, and thirteen chapters, nine of which are on the subject of rhythm, and the other four on discant. "Measured music," he says, "is song measured by long and short times, and these times may consist either of sound or of rests; I speak of a rest as measured by time, because otherwise the performers of two different parts, one of which should have a rest, and the other not, would be unable to proceed together in exact time." This seems to imply something more than simple counterpoint. The details into which he enters show clearly that it is to the *organ* and *organising* that measured music owes its origin. He distinguishes three kinds of *duration*, long, breve, and semibreve, for which he gives notes with corresponding characters for their *rests*. The *long* may be perfect or imperfect. It is perfect when it is equal to three *breves*, because this number is the emblem of the Trinity. It is imperfect when it is equal to two *breves*. Besides their proper values these notes have a great many accidental properties, into the detail of which it would be useless to enter. He distinguishes five modes or moods of rhythm. The first consists of *longs*, the second of a *breve* and a *long*; the third of a *long* and two *breves*; the fourth of two *breves* and a *long*; and the fifth of *breves* and *semibreves*. Franco also

makes use of bars drawn across the staff, to mark the ends of a sentence or verse; and this is the only use that is made of bars at present in canto fermo.

"I have been able," says Dr. Burney, "to find no considerable improvements in the time-table between the eleventh and fourteenth century; when the chief merit of several authors in the cantus mensurabilis, whose names and writings have come down to us, was to dilute the discoveries of Franco, and pour water on his leaves."

36. About the end of the fourteenth century, musicians began to abandon the rhythmic feet of Franco, and to introduce into the measure as many sounds as the different subdivisions of time furnished them. New figures of notes became necessary, and were introduced about the beginning of the fifteenth century. Prosdocimo, who wrote in 1412, does not mention those additional figures; but in later authors we find them distinctly described; and among the first by John Tinctor, who was chapel-master to Ferdinand king of Naples, in the latter half of the fifteenth century. Tinctor is remarkable as the author of the first dictionary of music, which he published under the title of *Definitorium terminorum Musicæ.*

37. The doctrine of Tinctor is much more fully developed in the writings of Franchinus Gaffurius, surnamed Laudensis, from Lodi in the Milanese, the place of his birth. He was born in 1451, and became chapel-master of the cathedral of Milan in 1484. The publication of the works of Gafforio is a remarkable era in the history of music, both on account of their own merit, and as being among the first which issued from the press. His *Pratica Musica* was printed at Milan in 1496. This work is divided into four books. The first treats of *harmony*, that is to say, of intonation or melody, for at that epoch the word *harmony* had still the same signification as among the ancients; the second, of measured song, the third of counterpoint, and the fourth of musical proportions.

Franchinus speaks of only five characters for time; the maxima or large, the long, the breve, the semibreve, and the minim. But other writers, early in the sixteenth century, added to these the crotchet, the quaver, and semi-quaver.

38. The use of bars to divide the period into equal measures, and to mark the rhythm by accents, did not take place till the beginning of the seventeenth century. Hence the perplexity of the old notation of time, of which the reader may form a notion from Rousseau's Dictionary, art. *Ligature, Mesure, Mode, Prolation*, &c. After this invention, the ancient notes of time, which signified a greater duration than that contained between two bars, or one measure, fell into disuse; the longest note is now the semibreve; and the convenience of marking the lesser accents, by uniting in groupes the tails of quavers, semiquavers, &c. has contributed to make composers prefer writing in these shorter characters of time, which gives modern music a different appearance to the eye from the ancient, even where the same proportions subsist in the duration of the sounds.

39. Franchino's third book treats of counterpoint, and he lays down eight rules for the succession of consonances, which are nearly the same as are observed to this day. He treats also of dissonances, and we see that these intervals were used at that time, but with timidity, and only as passing notes, or by syncopation.

40. The practice of figurative discant very soon followed the invention of the time table. Even Franco's definition of discant might be construed to imply it. "Discant is the consonance of different melodies, in which these different melodies move in sounds of various lengths, as longs, breves, and semibreves, proportioned to each other, and expressed in writing by adequate notes or characters." Whether this definition means that the different melodies in their simultaneous agreements were of different figures, two or more notes of the melody harmonising with one note of the other, may admit of question; but there is no doubt that figurative or florid counterpoint, imitation and fugue, are to be referred to a very early period. It is certain that the first compositions for the church that were printed, and which were composed in the fifteenth century, are full of canons and fugues of the most artificial and difficult construction. The origin of these contrivances is thus accounted for by Dr. Burney.

41. "Padre Martini is of opinion that this species of composition had its beginning in the following manner: The first composers having begun to add another part to *canto fermo*, which, at the same time that it formed a different melody, was in harmony or counterpoint, which is the union of different melodies, contrived that whatever part they superadded to the chant, should resemble it as much as possible, if not throughout the movement, at least in the subject." This we may easily suppose would be suggested by the antiphonal singing, in which one choir sung a short sentence, which was answered by another choir. "But as this canto fermo is sometimes transposed from one hexachord (or *proprietà del canto*,) to another, in the same manner the imitations of the several parts in counterpoint are made, sometimes in unison or octave, and sometimes on the 4th or 5th above or below; still taking care that the intervals and syllables, or solmisation, are the same with those of the principal chant. And it is easy to discover, from the skeleton of the ecclesiastical modes, given in art. 17.) that this is the true original of fugue, and all the laws of reply. If these fixed and fundamental sounds were filled up with their intermediate sounds, we should have all the scales whence the melody of fugues and canons was drawn, during almost three centuries. The chants of the church furnished the subjects and their answers; the accuracy of which was proved by the syllables of the Guidonian hexachords. The 5th above, and 5th below, or 5th and 4th of the key, either major or minor, are its first relatives; and as they furnish the most agreeable modulation, so they are the only intervals, different from the identity of unison and octaves, in which the answer of a regular canon or fugue can be made. All other replies are allowed by theorists to be nothing but imitations. And the literal names of the notes, their appearance on paper, or even their effect on the ear, will not demonstrate the truth of an answer with such certainty as solmisation; and it seems as if the Guidonian syllables would be more useful in this species of composition than in singing.

"I have dwelt the longer on these first principles of Canon and Fugue, as the lives and labours of the primitive fathers of harmony were spent in establishing, and those of their immediate successors in producing such illustrations of them, as were not only the delight of their own age, but are still the admiration of every friend to the art."

42. Both Tinctor and Franchinus ascribe the invention of florid counterpoint, or figurative harmony, to the English, and specifically to John Dunstable, who died in 1453, or 1458. This *new art*, as Tinctor calls it, was soon after cultivated with success in the different countries of Europe; and from this period downwards, not only the names of composers are known, but many of their works are preserved. It was our intention to exhibit progressive examples of ancient composition; but this would occupy too much of our limited space. We must therefore be contented with mentioning the chief of these venerable masters, and giving a general account of their harmony, and of the progress of the art towards its present condition.

43. The Netherlands took the lead of the rest of Europe, and produced, from the close of the fifteenth century downwards, John Okenheim, his scholar Josquin Des Prez, or Jodocus Pratensis, who was deservedly reckoned by his contemporaries the greatest musician of those times; Henry Isaac, Jacob Horbrecht, who was music master to the celebrated Erasmus. It is related of him, on the authority of Erasmus, that he composed an excellent mass in one night, which was very greatly admired by the learned.

44. At this time the Netherlands furnished masters to the rest of Europe; even Italy did not disdain to take her instructors from that country. Adrian Willaert settled at Venice, and is regarded by the Venetians as the head of their school. His scholar, Gioseffo Zarlino of Venice, the most celebrated and voluminous theorist of the 16th century, published *Demonstrationi Harmoniche*, in 1571. Gaudio Mell, a Fleming, supposed to be the same with Goudimel, a native of Franche Compté, was the master of the celebrated Giovanni Pierluigi da Palestrina, from the place of his birth, the ancient Praeneste. This great musician is justly considered as the head, not only of the Roman school, but of ecclesiastical musicians. The rage for learned and intricate contrivances, and crowded harmony, was carried so far, that the church services tended only to distract or amuse, instead of assisting devotion. Pope Marcellus the Second, it is said, had come to the resolution, in the year 1555, of entirely suppressing choral singing in the church. The Bull was already prepared, and on the point of being promulgated, when Palestrina, at that time in his 26th year, entreated his holiness to suspend the decree till he should hear a mass composed in what he, the author, conceived to be the true church style. The Pope granted his request; and was so delighted with the purity of the harmony, and facility of the style, that the design was laid aside. The compositions of Palestrina are still continually performed at Rome.

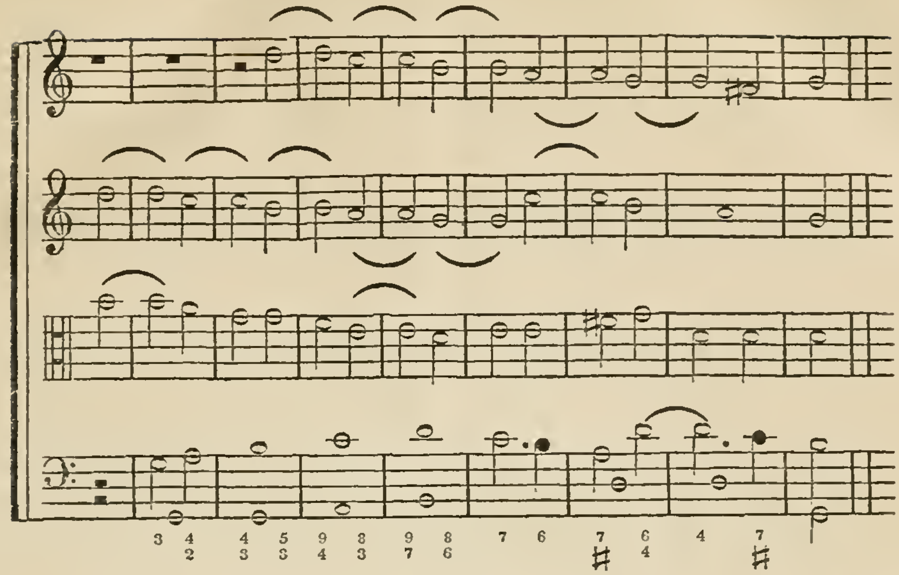
45. At this epoch, the general rule for harmony was to accompany every note of the scale with its own common chord, except those which rise by semitone, which had a chord of the sixth: and it is this which gives those ancient compositions their peculiar character and effect. It was towards the middle of the 17th century, that the key and mode were generally well ascertained, and that the harmony of the scale was reduced to that of the key-note, of the fourth and of the fifth of the key. At the time we are speaking of, discords were used chiefly as passing notes, or by syncopation. "The old contrapuntists," says Dr. Burney, "held the sharp (major) fourth, and flat (lesser) fifth in such abhorrence, that, to avoid them, they frequently made the seventh of the key flat, even before a close." This observation is applicable, however, to an earlier age than that of Palestrina. "Whoever," says the Doctor, in another place, "first combined the sharp 3d and 7th to the 5th of the key, and inverted this chord into $\begin{smallmatrix}6\\4\\3\end{smallmatrix}$ to the second, $\begin{smallmatrix}6\\5\end{smallmatrix}$ to the sharp (major) seventh, and $\begin{smallmatrix}6\\4\\2\end{smallmatrix} +$ to the fourth of a key, conferred as refreshing a benefit on the craving lovers of music, as Moses on the thirsty Israelites, in producing water with his wand from the rock on Mount Horeb. These combinations, though unknown to the old masters, are utterly indispensable in the present *Regle de l'Octave*. The combinations are found in the compositions of Palestrina, used in a regular manner; but always prepared, and very sparingly. They seem not to have been considered, as in the present day, a constituent part of harmony, next in importance to the chord of the key. The old masters seldom or never add the seventh to the leading chord in a close on the key; but the major third of the leading chord ascends by semitone to the octave, as at present.

46. While the old masters were thus eagerly engaged in improving harmony, and exerting their ingenuity and industry in Canon and Fugue, melody or air was in a great measure neglected. *Air* had no existence but in the national tunes of different countries, handed down, perhaps by tradition, from the songs of the Troubadours, the wandering minstrels of the age of chivalry; or produced by unknown jongleurs and violars, as dance tunes. About the middle of the 16th century, musicians began to harmonize these tunes, and to compose variations to them for keyed instruments. "The first secular music in parts," says Dr. Burney, "that I have been able to discover on the Continent, is the harmony that was set to the rustic and street tunes of the kingdom of Naples; and these under the several denominations of *Arie*, *Canzonette*, *Villotte*, and *Villanelle alla Napolitana*, were as much in fashion all over Europe, during the 16th century, as *Provençal* songs were in preceding times, and *Venetian* ballads have been since. Besides the old tunes, which were collected and published in four parts, others were composed, not only by the natives, but in imitation of these short primitive airs, by almost all the principal composers of other places, of which innumerable volumes were printed at Venice, Antwerp, and elsewhere, under the same titles. Indeed, with respect to Air, which consists in symmetry and grace, it was long unprincipled; and, till the establishment of operas, no better was perhaps produced than are to be found among the Neapolitan *Villanelle*: for during these times even the key was seldom ascertained; and the number of bars are, indeed, still more regular by chance and sensibility, perhaps, than principle. The repetition of a lucky series of notes, by which they are more deeply impressed on the mind of the hearer, was hardly begun to be practised so late as the sixteenth century; though in the next, the secret was not only found, but men of small genius and resources availed themselves of it to a disgusting degree."

47. At the same time another species of secular music prevailed, under the name of *Madrigals*. These were vocal compositions in many parts, generally in fugue. They do not seem to have contributed greatly to the improvement of melody; but as greater freedom of combination and modulation were allowed, than in the church, these secular compositions afforded an opportunity to ingenious men of trying new effects, by which the bounds of harmony were enlarged.

48. One of the most successful of these innovators, was Claudio Monteverde, of Cremona. In 1582, he published Madrigals for three, four, and five voices, in the style of the times; but his courage increasing, he ventured, in subsequent productions, to violate many rules of counterpoint, which, having been long established, were held sacred by orthodox professors. He was severely attacked by many, and especially by Artusi of Bologna. Monteverde's licenses, however, pleasing the public ear, were soon adopted by all, and brought about a revolution in harmony. Since that time, every fortunate breach of an old rule seems to be regarded as the establishment of a new one; by which means, says Dr. Burney, the code is so enlarged that we may almost pronounce every thing to be allowable in musical composition that does not offend cultivated ears. Monteverde was the first who used double discords, such as the $\begin{smallmatrix}9\\4\end{smallmatrix}$, $\begin{smallmatrix}9\\7\end{smallmatrix}$, and $\begin{smallmatrix}7\\2\end{smallmatrix}$, as well as the lesser fifth and seventh, without preparation.

Monteverde's New Discords, in Five Parts.

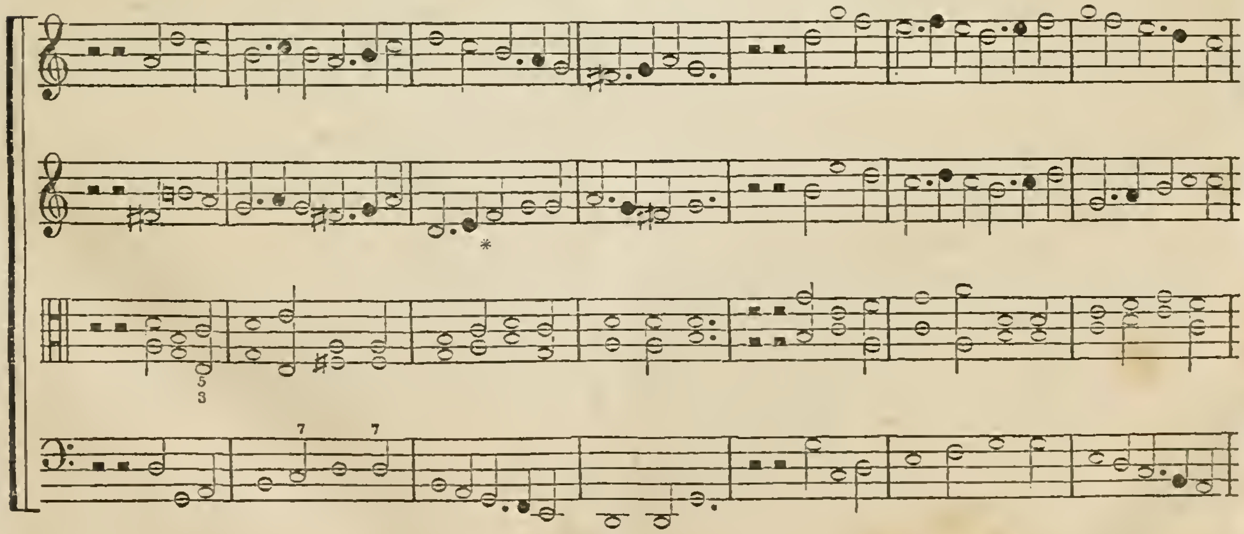


It was not only by the use of these discords that he improved music, for by quitting the ecclesiastical modulation in his secular productions, he determined the key of each movement, smoothed and phrased the melody, and made all his parts sing in a more natural and flowing manner than had been done by any of his predecessors.

49. The beginning of the 17th century is a notable era in the history of music. About the year 1600, the invention of *Recitative* by Jacopo Peri, at Florence, and by Emilio del Caveliere, at Rome, gave birth to the *Opera* and the *Oratorio*. The success of Peri's *musica parlante*, in his operas of *Dafne* and *Euridice*, which last was composed and performed at Florence, on occasion of the marriage of Henry IV. of France with Mary de Medici, excited the emulation of all the musicians of Italy; and their united efforts, and progressive improvements, brought melody to its highest perfection.

50. Monteverde was among the first who emulated Jacopo Peri, in his new invention. His opera of *Ariadne* had great success, and was among the first that were published with the music. From this opera we shall give, as a specimen of the harmony of that age, a dance tune, *alla Moresca*. It is composed in five parts, and being in simple counterpoint, is a better example of the harmonies a good composer chose, than a composition in fugue would be.

MORESCA. *Dance Tune in Monteverde's Opera of Ariadne.*



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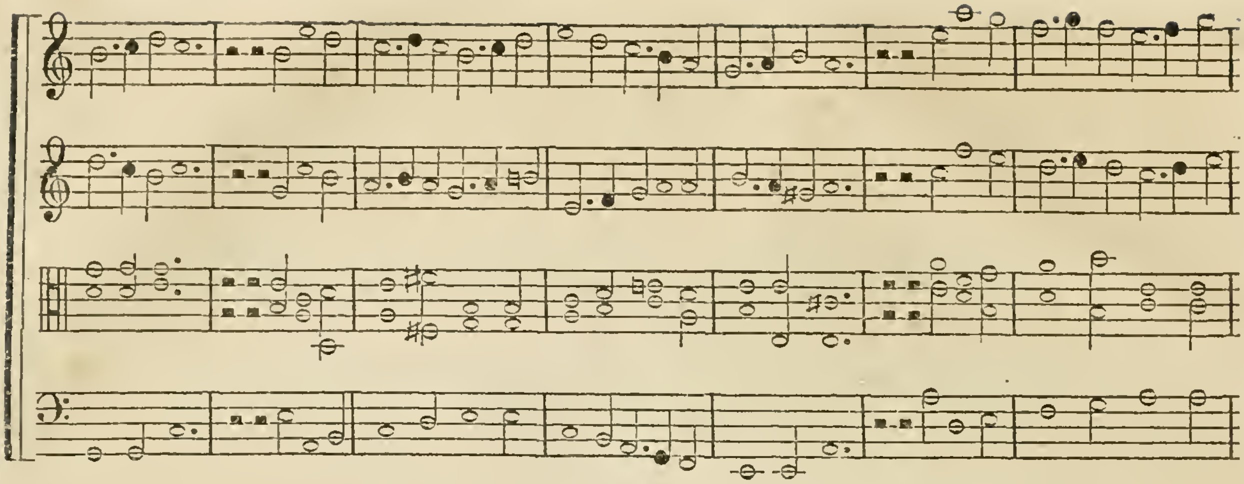
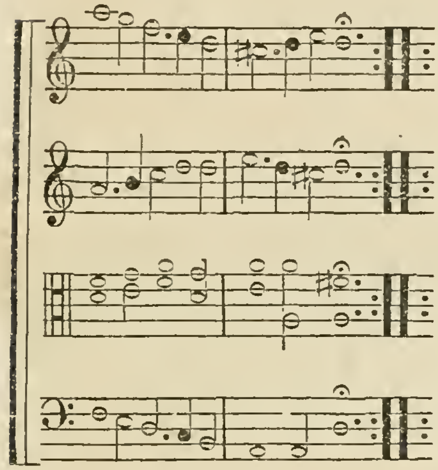
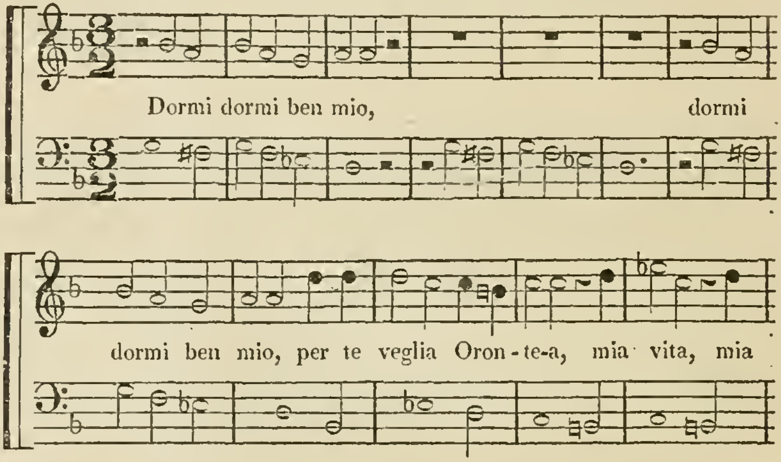
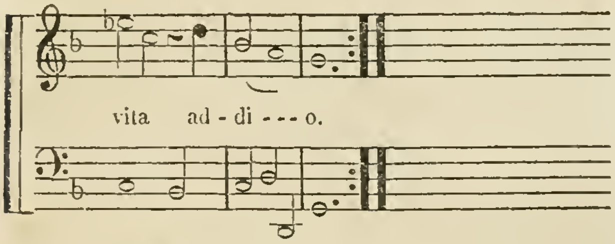
* The omission of a ※ here is certainly an error. This Moresca is copied from Sir John Hawkins' *History of Music.*





Aria nell' Opera d' Orontea del Cesti.





This *Moresca* consists of one strain, repeated in four keys, G and C major, A and D minor. We may ask, which is the principal key? There being neither sharp nor flat at the clef, seems to indicate C; but the air neither begins nor ends in that key. In the major mode the harmony is much the same as a composer of the present day might employ. To the third note in the bass, (A in the key of G, and D in that of C) a modern would prefer the chord of the greater sixth, second inversion of the dominant, to the common chord here given to it. The chord of the major 7th to the fourth of the key, resolving by the diatonic ascent of the bass on the leading chord, is not so usual now as it once was: the chord of the 6th or $\genfrac{}{}{0pt}{}{6}{5}$ is preferred. The ascent of the minor 7th of the leading chord in the melody, (3d bar) while the bass takes the third of the key, is a licence still practised by good composers. But the harmony in the two minor keys is very curious. The fifth of the key has a minor chord, though it is to be followed by the chord of the key. In A this is the case, even when the imitation of the air in the principal melody requires G♯. It is only in the final close that the leading chord has a major third; yet he has thought it necessary to give the fourth of the key (proceeding to the fifth) a major third. A modern composer would have just reversed the matter: He would have reckoned the minor harmony admissible to the fourth; but the major indispensable to the fifth. In both these minor strains the conclusion is a major chord, which the French call the *Tierce de Picardie*. The major common chord being reckoned the most perfect harmony, it was a rule in the church to end every composition with that harmony. Padre Martini recommends the practice, and Dr. Burney approves of it, in ecclesiastical music. In secular music, it is a rule more honoured in the breach than in the observance. These remarks show that music was not yet delivered from the trammels of the ecclesiastical modes, and that the minor mode, as now understood, was not as yet completely established.

51. It was a considerable time before opera music was entirely freed from the shackles of fugue and complicated contrivance, and before recitative was completely distinguished by its own phraseology. About the year 1635,

Giacomo Carissimi, of Rome, began to flourish. He banished formal cadences from his recitatives, and made them approximate more nearly to declamation, and, at the same time, gave new grace and expression to his vocal melody. In his works, and in those of his cotemporary Alessandro Stradella of Naples, there are to be found more traits of fine melody than in any other composers of the 17th century. Marc Antonio Cesti, of Venice, in the opera of *Orontea*, brought out in 1649, first introduced an air at the end of a scene of recitative, and contributed greatly to the improvement of both these species of melody. A short air from this opera is given as a specimen of Cesti's simple and expressive melody. Taken from Dr. Burney's History.

52. In the mean time instrumental music, properly so called, began to improve. Ludovico Viadana, if he did not invent, was at least the first who drew up general rules for the figures of thorough bass, and composed an *organ bass* different from the voice part. Girolamo Frescobaldi, of Ferrara, who flourished about the beginning of this century, composed fugues expressly for the organ, which were admired and imitated over all Europe. His *ricercari*, &c. were among the first compositions printed in score and with *bars*. *Ricercari* and *fantasie* preceded *sonatas* and *concertos*, and were the first compositions expressly made for instruments after the invention of counterpoint.

53. The violin kind of instruments may be traced to the ancient cithara. The first step towards the modern instrument, was the invention of a neck, by means of which the strings might be shortened during performance, so that a few strings furnished many sounds. This produced the lute, guitar, &c. In the latter name the ancient word cithara remains. But the capital improvement was the invention of the *bow*. From some ancient figures it appears that this instrument was in use in France, as early as the beginning of the fourteenth century; and even, as Abbe Le Beuf thinks, as early as the middle of the eighth. The instruments played by the bow were *viols*, with six strings over a fretted finger-board, besides several other strings towards the left, which produced chords to the higher part. The violin with four strings, and without frets, was despised, and left to strolling performers. About the beginning of the seventeenth century the value of this instrument began to be found out. In the orchestra, at the performance of Monteverde's opera of Ariadne, there were ten *Viole de brazzo*, and only two violins; *Duoi Violini piccoli alla Francese.*

The superiority of this instrument began to be felt; the best masters began to think it no degradation to compose for it. The frets were removed from the finger board, and instruments capable of perfect intonation took place of the old chest of viols.

54. The composer who contributed most to the favour of the violin, was the justly celebrated Arcangelo Corelli, a Bolognese by birth, but settled at Rome about 1683, when his first work was published. Soon after the publication of Corelli's works, the violin was universally esteemed the capital instrument, and a crowd of great performers and great composers for that instrument appeared. Nearly cotemporary with Corelli were Albinoni and Vivaldi. His greatest scholar was the celebrated Tartini. The style of this great performer was at first extremely difficult, but in 1744 he changed it entirely to graceful and expressive. Continual practice, when there is no natural inaptitude, will generally ensure the attainment of great execution; but grace and expression can be attained only by those on whom nature has bestowed taste and sensibility. Geminiani, another of Corelli's scholars, settled in England, and contributed to the national taste and improvement.

55. Alessandro Scarlatti, towards the end of the seventeenth century, was the father of the illustrious School of Naples. The immediate scholars of Scarlatti, and of his contemporary Gaetano Greco, were Leonardo Leo, Nicola Porpora, Domenico Scarlatti, who, by his happy licenses, removed many of the old restraints, Leonardo Vinci, who set the example of banishing from the theatre fugue and laboured contrivance, in which he was followed by Pergolesi and Hasse, Francesco Feo, Francesco Durante, &c. To these succeeded Jomelli, Sabbatini, Sacchini, Piccini, Paesiello, Guglielmi, Cimarosa, Sala, Tarchi, Sarti, Martellari, &c. &c. who have delighted, and still delight the lovers of music.

56. In England we may distinguish three periods in the history of music, since the invention of printing. The first ends early in the seventeenth century. "However inelegant, uncouth, and imperfect our lyric compositions may have been," says Dr. Burney, "till after the middle of the sixteenth century, our counterpoint and church-music arrived at a perfection with respect to art, contrivance, and correctness of harmony, about that time, which at least equalled the best of any other country." This period comprehends the names of Robert Fairfax, John Shepherd, Robert Johnson, Robert Parsons, Dr. Tye, Robert Whyte, Thomas Tallis, William Bird, author of *Non nobis Domine;* Thomas Morley, author of the *Introduction to Practical Musick;* Dr. Bull, Michael Este, Elway Bevin, and Orlando Gibbons. This last great musician died in 1625. The second period comprehends Dr. William Child, William and Henry Lawes, John Hilton, Matthew Lock, whose music in Macbeth is still performed; of whom Dr. Burney says, that he was the best secular composer our country could boast, till the time of Purcell; Pelham Humphrey, Michael Wise, Dr. Blow, and the celebrated Henry Purcell, who died in 1695. The third period extends from the death of Purcell to the present times, and includes the names of Dr. Holder and Dr. Aldrich, who, though not musicians by profession, were excellent composers for the church; Dr. Crofts, Dr. Green, Mr. John Weldon, Dr. Boyce, Dr. Nares. In theatrical music, the great boast of the English is Dr. Arne, the only native musician who has, since the days of Purcell, enjoyed an equal degree of popularity with that admired master. Dr. Arne died in 1778.

57. The French have been always delighted with their own music, and in this they have always enjoyed an exclusive monopoly, at least as far as regards vocal music. "French music, at least vocal," says Voltaire, "is not relished, and cannot be relished by any other nation, because French prosody is different from that of all Europe. We lay the stress always on the last syllable, and all other nations on the penult or antepenult, like the Italians. Our language is the only one which has words ending in *e* mute; and these *e's* which are not pronounced in ordinary declamation, are uniformly pronounced in our musical, *gloi-reu, victoi-reu, barbari-eu, furi-eu.* This is what makes most of our airs, and our recitative, insupportable to those who are not habituated to it. This, together with the slowness of our melody, which forms a strange contrast with the vivacity of our nation, will always make our music fit only for the French."—"Our instrumental music partakes a little of the monotony and slowness with which our vocal is reproached; but several of our symphonies, and especially our dance-tunes, have received more applause in other nations, and they are performed in many of the Italian operas. There are hardly any other admitted by a sovereign who has one of the best operas in Europe, (the king of Prussia) and who, among his many singular talents, has condescended to cultivate music with great care.

"John Baptiste Lulli, who was born at Florence in 1633, and brought to France at the age of 14, before he had learned to play on the violin, was the father of true music in France. He knew how to accommodate his art to the genius of the language; which was the only way to succeed. It is worthy of remark, that at that time Italian music had not departed far from that gravity and noble simplicity which we admire in the recitatives of Lulli.

"After him all our musicians, such as Colasse, Campra, Detouches, and the rest, have been his imitators, till at last one man came, who has risen above them by the profoundness of his harmony, and who has made music a new art."

It is of Rameau that the celebrated author speaks in the last sentence. This theorist, to whom music lies under real obligations, was long cried up in France as the author of musical science. Now the tide of his popularity is turned, and even the French themselves seem disposed to deny him any merit whatever. "His system," says M. Choron, "which was never received in Italy or Germany, is now universally rejected, even in France; and is only followed by a few composers, who, having been educated in his principles, would find too much difficulty in renouncing long-since contracted habits. It is therefore with much injustice that Rameau has been proclaimed as the founder of the science of harmony, and as having at last found in nature the principle which connects the scattered rules of former times. If these eulogiums have been repeated by entire academies, and by writers of the first order, such as D'Alembert, Rousseau, Condillac, and others, this only proves the danger of speaking on a subject which one does not understand. All the chords, all the rules of harmony, and the principles of composition, existed several ages before him. To be well understood, they needed only to be presented with order; in place of which he has only augmented the confusion, and destroyed any school there was in France, by introducing a vicious system, which being put in order by able writers, held out to laziness the attractions of a deceitful facility. Still we should acknowledge, that we have to this artist, in other respects estimable, one great obligation—that of having turned the general attention to the consideration of *inversions*, which, being developed by more able hands, and especially by Marpurg, Padre Martini, Knecht, Vallotti, Sabbattini, &c. has furnished an excellent method of classing chords."

58. Music has been long successfully cultivated in Germany. If, in justice, we must allow the admirable Italian composers for the theatre to have carried melody and expression to the highest perfection, the Germans have been their successful followers in that style, and have even excelled them in instrumental composition. During the 16th and 17th centuries, the German composers were at least equal to those of any other country in Europe, as far as harmony and contrivance were concerned. "But during the present century," (that is, the 18th) says Dr. Burney, "by a more frequent intercourse with Italy, and the best compositions and vocal performers of that country, with the establishment of Italian operas in all the principal courts of Germany, the inhabitants of that vast empire have cultivated music to a degree of refinement, particularly intrumental, beyond any period in the history of the art, and have not only supplied their own country with innumerable great musicians, but exchanged with Italy, and furnished every part of Europe with professors, whose talents and abilities have been the delight and admiration of all true judges of composition and performance." During the 18th century, Germany has produced so many excellent musicians in every style, that we must be contented with naming only the most distinguished. The great opera composers are Handel, Hasse, Graun, Gluck, John Christian Bach, Nauman, Haydn, and Mozart. Instrumental—Teleman, Handel, Sebastian Bach, the father, to use Mr. Shield's words, of a wonderful family of harmonists; Emanuel Bach, John Christian Bach, already mentioned, Kirnberger, Quantz, music-master of the great Frederick, king of Prussia, Stamitz, Cramer, Ditton, Eckard, Eichner, Hoffman, Schobert, Schroeter, Schwardt, Vanhal, Wagenseil; above all, Hadyn, Mozart, and Beethoven; to whom we may add Pleyel and Kozeluch, with innumerable others. Germany is, perhaps, more truly the country of music, than any other in Europe. It makes a part of the business of almost every common school of every town and cottage, so that genius has the opportunity of early instruction; and the patronage and even example of the princes of the empire, gives every encouragement to the exertions of professed musicians.

For a more particular account of the history of music, the reader is referred to *A General History of Music*, by Charles Burney, Mus. D., and *A General History of the Science and Practice of Music*, by Sir John Hawkins. Also the lives of eminent musicians under their respective names, as Handel, Haydn, Mozart, &c.

INTRODUCTORY REMARKS.

59. For the purposes of music, sounds must be agreeable in themselves: they must have that clearness which distinguishes them from mere noise, and that sweetness which distinguishes them from harsh and disagreeable sounds. In these respects there are many shades of difference, which constitute the different qualities of musical voices and instruments, and which consequently claim the regard of the musician. But the chief object to be considered in the science of music, is the relation of sounds to each other, in respect of gravity and acuteness. Happily we are able to ascertain and describe these relations in such a manner, as to convey the most precise notions of them, and even subject them to numerical calculation, like any other quantities.

60. Sound is caused by the vibrations of sounding bodies, which communicate similar vibrations to the air, which last affect our organs of hearing. When the vibrations of the sounding body, and consequently those of the air, are of *uniform velocity*, that is, when the numbers of vibrations in equal times are equal, our organs of hearing are *uniformly* affected, which we express by saying that the sound continues at the *same pitch*. If by any cause the velocity of the vibrations be increased, the sound is perceived to be what we call more *acute* or *sharp;* and if by any cause the velocity of the vibrations be retarded, the sound is perceived to be what we call *graver* or *lower*. When the accelerations or retardations are gradual, so that the alterations of acuteness or gravity take place by *insensible* degrees, the sound is *continuous*, and is not properly musical; (such for example, as is produced by sliding the finger along the string of a violin, while it is acted on by the bow.) When, on the other hand, the pitch is the same for some *ascertainable* time, and the alterations of acuteness or gravity take place by certain *ascertained degrees* or *intervals*, the sounds are musical; and one principal object of musical science is to ascertain those relations in the pitch of different sounds, which are proper for producing music.

That we may be able to reason concerning the different relations of musical sounds, it is necessary that we be possessed of some unequivocal method of determining or defining them; and the most convenient is found to be the *division* of a musical string. There are three circumstances which determine the number of vibrations made by a string in a given time, or, in other words, the pitch of its sound, viz. the length of the vibrating string, the weight of a given portion of it, and the force with which it is stretched. By supposing these two last circumstances always the same, the pitch of musical sounds can be very conveniently expressed by the *length* of the strings which respectively produce them. It has been demonstrated that the numbers of vibrations are inversely proportional to the lengths; consequently unisons are of the same length: the string of the more acute sound is shorter, and that of the graver sound longer.

61. We shall here show the relative proportion of the strings, which give the simplest scale of musical sounds. When the sound of a string is compared with that of one-half its length, the latter is *octave* higher than the former; so called because such is the relation of the eighth sound of the scale. The relation between a note and its octave is, next after that of unison, the simplest and most perfect in nature; and when the two notes are sounded at the same time, they almost entirely unite. Indeed so striking is the resemblance of the one sound to the other, that it often requires care and attention to distinguish them from unisons. It is for this reason, that by whatever name or letter any sound in a scale is denoted, its octave is denoted by the same name or letter; and should we divide the string which gave us the octave to the former, again by 2, so as to obtain its octave, this new sound, whose string is $\frac{1}{4}$ of the first, is called its double octave, and is still denoted by the same letter; and so of $\frac{1}{8}$, or the triple octave, &c. In like manner, should we take a string double in length of the first, it would give a sound octave below it, that again doubled, its double octave below, and so its triple octave below, &c. And all these sounds, given by strings in the proportion of 8, 4, 2, 1, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, &c. are denoted by the same letter, and are considered as repetitions of each other. Hence, when we fill up one octave with its proper intermediate sounds, we describe the whole system of musical intervals. It is plain from this statement, that if we should use no other proportions than that of equality, and those obtained by bisection, we could have no other musical intervals than unisons, octaves, double octaves, &c. But if we take $\frac{2}{3}$ of the primary string, we obtain that sound which is fifth in the scale, and if we take $\frac{4}{5}$ of the primary string, we have the sound which is third in the scale. By combining these ratios, the whole system of musical relations is obtained.

62. Thus, if we take a fifth to the fifth of the scale, we take $\frac{2}{3}$ of $\frac{2}{3}$, that is $\frac{4}{9}$ of the primary string. As $\frac{4}{9}$ is less than $\frac{1}{2}$, it is plain that this sound is more acute than the octave; but by doubling it, that is, taking its octave below, we have $\frac{8}{9}$ of the primary string, and as this is greater than $\frac{4}{5}$, it is an intermediate sound between that of the primary string, and the third of the scale. It is the second of the scale. If we take a string, such that the primary string shall be fifth to it, its length will be expressed by the improper fraction $\frac{3}{2}$, and taking its half in order to have its octave, we have $\frac{3}{4}$ of the primary, which it is plain will be an intermediate sound between the third and fifth; it is the fourth of the scale. If we take a fourth to the third of the scale, or a third to the fourth of the scale, it will be $\frac{3}{4}\times\frac{4}{5}=\frac{12}{20}=\frac{3}{5}$; this is the sixth of the scale, somewhat more acute than the fifth. Lastly, if we take a fifth to the third, or a third to the fifth, it will be $\frac{2}{3}\times\frac{4}{5}=\frac{8}{15}$, which is the seventh of the scale, somewhat graver than the octave. See Acoustics, Apotome, Comma, &c. &c. Farey's Notation, Interval, Vibration.

63. Such calculations are applicable to many practical purposes in music. They enable us to estimate the results of any series of the intervals taken truly, or the effect of such alterations of them, as may be necessary in tuning some instruments. They furnish the principles on which musical instruments must be formed, or by which the imperfections of instruments may be remedied. But we should very much mistake the matter, should we suppose, that from the consideration of these proportions, we should be able to deduce the rules that are to guide the musician in the use of musical intervals. Such an attempt has been frequently made, but has always proved abortive. Speculative inquirers may please themselves, by finding a physical cause of the pleasure given to the ear, by certain combinations, in the coincidences of their vibrations; but they could never derive from such speculations, one practical rule to guide the composer. If, for instance, they find that a fifth or octave is pleasing, because of the frequent coincidence of the vibrations, they could never have foretold that such intervals taken successively, between the same parts, in similar motion, would be offensive, but agreeable in contrary motion. Nor when experience has found the rule, can they assign any reason for it. The truth is, our knowledge of the causes of our sensations is imperfect and uncertain; the sensations themselves are immediately subjected to our observation and reflection: the direct appeal to them is, therefore, the only rational one. The rules of music, like the common law, are to be sought for in the collected decisions of competent judges, who, in the course of time, have successively pointed out what combinations and progressions are good, and what displeasing, and have thus gradually refined and improved the art. Music is a language; and there is a striking analogy between this science and grammar. Whoever would understand any language, or acquire its use, must apply to the rules of grammar, founded on the practice of those who speak or write it:

> \- - - - - - - - - - - - - - - *usus,*
> *Quem penes arbitrium est, et jus et norma loquendi,*

and he would be very ill advised, who should forsake these common rules for the metaphysical speculations of Harris or Horne Tooke.

64. M. D'Alembert has very successfully exposed the mistake of those who seek the foundations of musical science in geometrical, arithmetical, and harmonical progressions, or in metaphysical speculations. Yet he seems to have exposed himself to a similar censure, in endeavouring after Rameau, to found it on one experiment. The desire to reduce every science, or branch of human knowledge, to some one principle, and thence to deduce the whole theory, has long prevailed among philosophers. This we cannot help thinking a very mistaken aim. It seems to us to resemble the conduct of an architect, who, to show his art, should prefer placing a pyramid on its small end, rather than on that broad basis on which it would firmly rest. The experiment on which Rameau, and after him D'Alembert, seek to build the whole science of music, is this. When a sonorous body is struck till it gives a sound, the ear, besides the principal sound and its octave, perceives two other sounds, very high, of which one is the twelfth above the principal sound, that is to say, the octave to the fifth of that sound; and the other the seventeenth major above the same sound, that is to say, the double octave of its third major. This experiment is certainly very curious. But there is another experiment which M. D'Alembert has not noticed, which, as we think, involves the true principle of the science, viz. that these sounds, or their octaves, heard simultaneously or successively, are extremely agreeable to the ear. When instead of this *experiment*, he tells us, that these sounds please,

because they are the immediate production of nature, he appears to us to be more wide of the mark than those who incurred his censure, in seeking to account for the pleasure given by consonances, from the coincidence of the vibrations. Yet M. D'Alembert tells us, that for want of knowing this experiment, preceding artists had been obliged to grope in the dark; as if major thirds and perfect fifths, had been concealed from the musical world, till this experiment discovered them; or as if this experiment had thrown any light whatever on the fact, that these are agreeable to the ear. In truth, M. D'Alembert, with all his ingenuity, has found difficulty to tack to this experiment the rules of composition; and so far from throwing any light on the science, the endeavour serves only to render dark and perplexed, what is very plain when laid down as a practical rule. If M. Rameau has contributed something to the arrangement of the rules of harmony, by turning the attention of musicians to the method of fundamental basses, that advantage rises out of the method itself, and not in the most distant manner from the experiment with which he endeavours to connect it.*

65. The rules of harmony may be regarded in various lights, and variously arranged, and one arrangement may be more luminous than another, or lead more easily to a knowledge of the doctrine to be taught. But so long as the doctrine is the same that is put in practice by the best masters, *one system* cannot be said to be more true than another. The doctrine taught in the systems, as they are called, of Rameau, Marpurg, Kirnberger, or Kollman, is the same at bottom, and therefore all are equally true. This is an observation that writers on the subject of music have overlooked, when they have sought to establish their own particular system as exclusively true. The rules of Etymology or Syntax of the Greek and Latin languages, given in the Eton Grammars, differ in many respects from those given in the grammars of the same languages, taught in this northern part of the island. Yet it never occurred to the grammarians of the one country, *to confute* those of the other. The doctrine of both is the same, being founded on the real practice of those who wrote the languages, which the grammarians undertake to teach. We cannot therefore but regard it as a narrow view of the subject, which such writers take, and cannot but think that the pages which they have devoted to the exclusive establishment of their particular theories, and the controverting those of other excellent writers, might have been occupied with matter more profitable to their readers. So far, therefore, from adopting the peculiar views of any one teacher, or from seeking to advance *a system* of our own, we think we shall better consult the advantage of the student, by sometimes placing the same subject in different points of view.

THEORY OF MUSIC.†

CHAP. I.

OF SCALES, INTERVALS, AND NOTATION.

66. MUSICAL sounds are arranged in order, as they become gradually more and more acute in the scale, which is usually sung to the syllables do, re, mi, fa, sol, la, si; or which is denoted by the letters C, D, E, F, G, A, B. This scale is heard when the long or white finger-keys of the piano forte are struck successively, beginning with C, and proceeding towards the right hand. The scale is so called from the Latin or Italian word *scala*, which signifies a ladder or stairs. When from the gravest or lowest sound we proceed to the higher or sharper sounds in their order, we are said to go up, or to ascend the scale; and when we proceed in the contrary direction, we are said to go down, or to descend the scale.

67. The steps, or degrees of this ladder, or scale, are not all equal. The first step, from C to D, is called a tone; the next step, from D to E, is similar, and is also called a tone; but the third step, from E to F, is immediately perceived by the ear to be of a different kind. F is much less removed in height or sharpness, from E, than E is from D, or D from C. The step from E to F is called a semitone. The three next degrees from F to G, from G to A, and from A to B, are all tones. If we wish to extend the scale still higher, the ear peremptorily requires that the next step from B to an eight sound should be a semitone; and we feel that this eight sound is necessary to make the ascending scale completely satisfactory to the ear.

When we compare this eighth sound with C, the lowest sound of the scale, we are immediately sensible that the two sounds have a very great resemblance to each other; and if the two sounds be struck at the same time, we feel that they almost entirely unite in the ear. The relation of these two sounds is indeed so intimate, that they are considered as replications or repetitions of each other; insomuch that they have both the same name C. The higher note is called an eighth, or octave, above the lower, as this is called an octave below the higher.

68. Should we also take octaves above all the other sounds, D, E, F, G, A, B, we should have another scale of sounds proceeding from the second C, exactly similar to the former in all its steps, and denoted by the same letters or names, c, d, e, f, g, a, b. In order to show how truly these two octaves or scales, are repetitions of each other, let a male and a female voice sing the scale together; those who have never before attended to the observation, will believe that the two voices are singing the same sounds; but, on a careful attention, it will be found that the female voice is all along singing octaves above the male voice. In like manner, should we take octaves below all the sounds of the first scale, we should have a third scale exactly similar to the two former in all the degrees; and so the scale, or scales, may be carried as far upwards or downwards as may be required. Keyed instruments generally comprehend five or six octaves.

69. This scale, in which the octave is divided into tones and semitones, as its elements, or smallest parts, is such as is furnished by keyed instruments in general. It is proper, however, to observe, that it is imperfect and defective. When the series of sounds is taken exactly as the ear desires them to be, other distinctions are found among them; with

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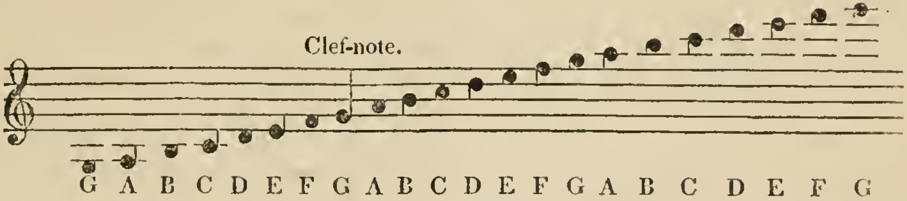
* This curious experiment was first made and described (as far as we know) by the celebrated Father Mersenne, in his *Harmonia Universalis*, published in 1636. He endeavours to account for the production of the different sounds, by supposing that the same particle of air which had been put in motion toward one side of the string, returns with the same velocity, and is again repelled with double velocity, which produces the octave, and by another return acquires a triple velocity, which produces the twelfth, &c.

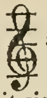
† By the THEORY OF MUSIC, we mean a systematic or well arranged account of its principles and rules. The knowledge of these is the science of music, and the THEORY teaches this science. It is necessary to give this explanation, because by the *Theory* of music is generally meant, either an inquiry respecting the foundation of the rules of the art in the nature of things, which speculations we hold to be idle; or the doctrine of ACOUSTICS, which is a separate science, although music derives from it the method of calculating its intervals.

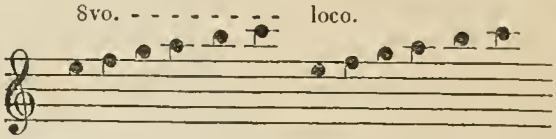
these, however, we will not perplex the student at present, reserving an account of this matter to the sequel.

70. This simplest scale, consisting chiefly of degrees of a tone, is called the *diatonic* scale, to distinguish it from other scales, in which the octave is divided into other elements, with which we shall afterwards get acquainted. It has also the epithet *major*, to distinguish it from another scale, called the *minor diatonic* scale—which distinction will be explained bye and bye.

71. Whether the analogy which we conceive between the relative qualities of sound, which we denote by the words grave and acute, and the relative qualities of space, which we denote by the words low and high, be really founded in nature, or whether it be merely imaginary, and familiar to us by habit, we shall not stop to inquire; but on this analogy musical language and notation proceed. Five lines ruled at small intermediate distances, are called the staff. The lines and spaces represent the degrees of the scale, and furnish a convenient method of denoting, by marks or notes placed on them, the relative height and depth, that is, the acuteness and gravity of the sounds. The lines and spaces of the staff are numbered from the lowest in the page upwards, and are called the 1st, 2d, 3d, 4th, and 5th lines, the 1st, 2d, 3d, and 4th spaces. If we agree to put the mark or note of G on the second line of the staff, the scale will be written thus—

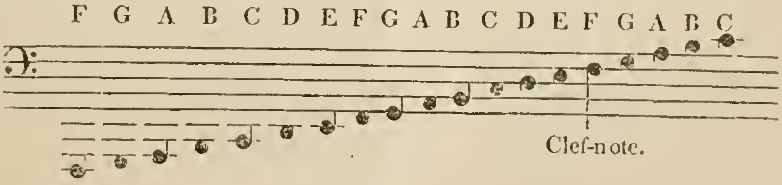


extending through three octaves. This character  at the beginning of the staff, represents the letter G, and it signifies that the note G is placed on the second line; and as this determines the place of all the other notes, the character at the beginning of the staff is called the G clef, from the French word signifying a key, because it explains this notation. Ascending the scale, from G on the 2d line, A will be on the 2d space, B on the 3d line, C on the third space, and so on; descending from G, F will be on the 1st space, E on the 1st line, D below the staff, and C (octave below that on the 3d space) on a short line called a ledger-line, or added line. This C, on the ledger-line below the staff in the G clef, is that about the middle of the key-board of the piano-forte, and is called middle C. Thus the exact pitch of the sounds expressed in this notation is determined. Descending from this middle C, B will be under one ledger-line, A on a second ledger-line, and G will be below two ledger-lines. In like manner the higher octaves are written with ledger-lines above the staff. But as it is difficult for the eye to catch the number of the ledger-lines and spaces when they are many, it is usual to write the highest notes of the scale as in the immediately lower octave, and to signify the true sounds by 8vo, with a dotted line running along the passage, thus—

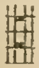


The Italian word *loco* is put after such a passage, to signify that the succeeding passage is to be read in its own place in the scale, as written. The G under two ledger-lines below the staff, is the lowest sound of the violin; and music for that instrument, for the flute, oboe, and other instruments whose scale extends no farther downwards, is written on the G clef; as is also in this country, the right hand part for keyed instruments, and vocal music for female or treble voices. This is also frequently called the treble clef; and the upper part of the scale is called the treble.

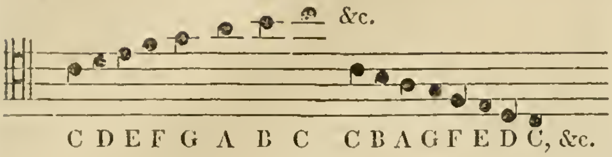
72. But it is obvious, that the lower part of the scale could not be written on this clef. Another, therefore, is used, marked thus 𝄢:, which is called the F clef, or bass clef. It is placed on the fourth line of the staff, and signifies that the F next below middle C is written on the 4th line. In this clef the lower part of the scale is written thus—



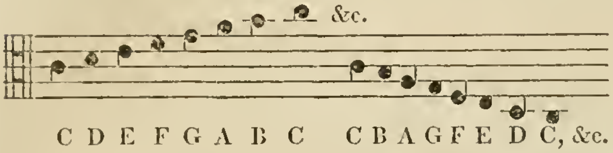
Music for bass voices and instruments, such as the basso, violoncello, bassoon, and the left hand part for keyed instruments, is written on this clef. Middle C, it may be observed, is on the first ledger line above the staff in the F clef, and the same C is on the first ledger line below the staff in the G clef; so that the highest line of the bass clef corresponds with the second ledger line below the treble; and the G, A, and B, here written on the 4th space, the 5th line, and above the staff, are the same notes which, in the G clef, are written by means of ledger-lines below the staff. This circumstance makes it extremely convenient to use these two clefs together for the right and left hand parts of keyed instruments. The F clef is sometimes placed on the third line instead of the fourth, in old music; but this practice is now obsolete, except in music for the church.

73. Though these two clefs comprehend the whole extent of musical sounds, yet the parts for instruments and voices which are called tenor and counter-tenor, whose compass comprehends the upper part of the bass and lower part of the treble, could not conveniently be written on either of them. A third clef is therefore used, marked thus  which represents the letter C, meaning the middle C of the scale of the piano-forte. This is placed on the fourth

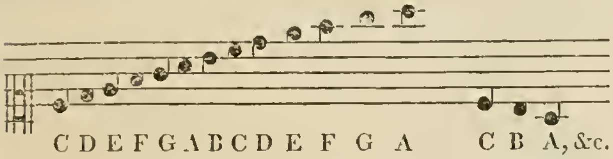
line of the staff, the two cross strokes including the line, thus—



When thus placed it is called the tenor clef. It is also placed on the third line, when it is called the counter-tenor, thus—

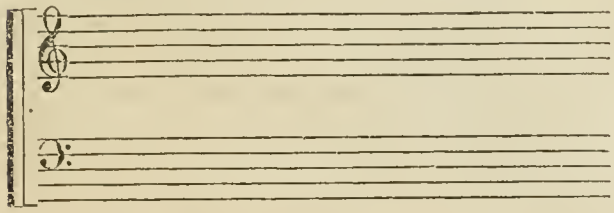


For treble voices, in foreign countries, this clef is usually put on the first line of the staff, and is called the Soprano clef; thus—



In Italy and Germany, no other clef is generally used for the right hand part of keyed instruments. In this country, many performers on keyed instruments are disposed to be contented with the knowledge of the G and F clefs; but the student who would peruse the works of the great foreign masters, must not yield to such indolence.

74. In music for keyed instruments, a staff being wanted for each hand, they are joined together by a brace, thus—



the upper part for the right hand, and the lower for the left: and in the same manner music for different voices and instruments is frequently written, which is called a *score*. The score brings the whole composition under the eye, and thus furnishes the most profitable lessons to the student. Let us now attend somewhat particularly to the *intervals* in the scale.

75. The word *interval*, means the difference in respect of pitch between two musical sounds. Thus, the first degree of the scale, from C to D, is the interval of a tone; from C to E, it is plain, is a greater difference in respect of pitch, or a greater interval; from C to F is an interval still greater, and so on. Intervals are named according to the number of sounds in the diatonic scale of which they consist, including both the lowest and highest sounds; and the reckoning is almost always from the lowest note upwards. The intervals so reckoned are denoted by corresponding figures. Thus, the interval from C to D is a second, and is denoted by the figure 2. The interval CE is a third, figured 3, because three sounds are to be named in reckoning it, viz. CDE; and if the two notes CE be sounded together, the resulting compound sound is called a third, although the intermediate sound D be omitted. So also CF is a fourth, CG a fifth, CA a sixth, CB a seventh, and Cc an eighth or octave, as before observed; denoted by the figures 4, 5, 6, 7, 8; and these intervals are so named, whether any of the intermediate sounds be heard at the same time or no. The interval from C to d (the second note in the octave above) is a ninth, figured 9. But it is to be observed, that musicians use the names and figures second, third, fourth, &c. even when the intervals are enlarged by octave, or by two or more octaves. Thus, the above interval C d is called also a second, and figured 2. C e is called a third, C f a fourth, C g a fifth, &c. Musicians seldom speak of tenths, elevenths, twelfths, &c. and still seldomer figure them, but as 3ds, 4ths, 5ths, &c. Intervals enlarged by one or more octaves, are sometimes called compound intervals.

76. It is necessary to attend particularly to the number of tones and semitones of which these intervals respectively consist. And here we must observe, that the semitone is reckoned, as the name implies, one-half of the tone, and, consequently, two semitones equal to a tone. This, as we shall afterwards learn, is by no means accurate; but it is sufficient for our present purpose.

The second, CD, is one tone; the third, CE, includes the intervals of two tones; the fourth, CF, consists of the intervals of two tones and one semitone; the fifth, CG, is one tone larger than the fourth, or it includes three tones and one semitone; the sixth is one tone larger, that is, it includes four tones and one semitone; the seventh, one tone more than the sixth, includes five tones and one semitone; lastly, the octave, one semitone larger, consists of five tones and two semitones.

77. But if we reckon seconds, thirds, fourths, &c. successively, from the other six notes of the scale, we shall find that the intervals of these names do not always consist of the same number of tones and semitones with these which we have just reckoned from C. Thus, counting from D, the second DE is a tone like that reckoned from C. But the third DF consists only of a tone and a semitone; whereas the third, counted from C, consists of two tones; and there is a very striking difference in the effect of these thirds. A third, consisting of two tones, is called a major third; and one consisting of a tone, and a semitone, a minor third. The fourth, reckoned from D, is of the same kind with that counted from C; for though the degrees of tone and semitone do not occur in the same order when we count from D to G, as when we count from C to F, yet we find the same number, namely, two tones and one semitone. The relation, therefore, of the two extreme sounds, D and G, is exactly the same as that of C and F. In the same manner, we find the fifth DA, and the sixth DB, to be of the same kind with those intervals counted from C. But the seventh DC consists of four tones and two semitones, or, calling the two semitones one tone, of five tones. It is, therefore, a semitone less than the seventh CB; which consists of five tones and a semitone. This last, then, is called a major seventh, and the other, DC, a minor seventh.

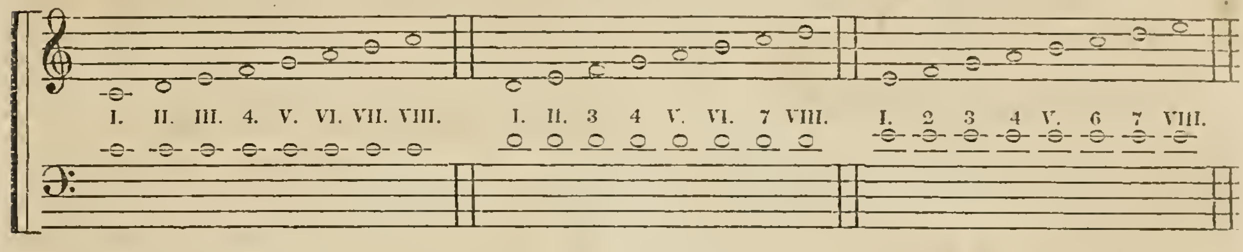
Counting from E, the first step to F is only a semitone. This is therefore called a minor second; and that of the interval of a tone, CD or CE, is a major second. The third, EG, is a minor like DF, the fourth EA, and fifth, EB, will be found to be of the same nature as those formerly reckoned. But the sixth, EC, consists of three tones and two semitones, and being thus reckoned a semitone less than the sixth before described, it is called a minor sixth, and the former a major sixth. The seventh, ED, is likewise minor.

If we reckon the intervals from F, we shall find them all of the same kind as when we reckoned from C, except the fourth, FB, which consists of three tones; and being thus a semitone larger than the fourth of our former reckoning, is called a major fourth, and the other a minor fourth. The major fourth is also sometimes called the tritone. The intervals, as reckoned from G, are similar to those counted from C, except the 7th GF, which is minor.

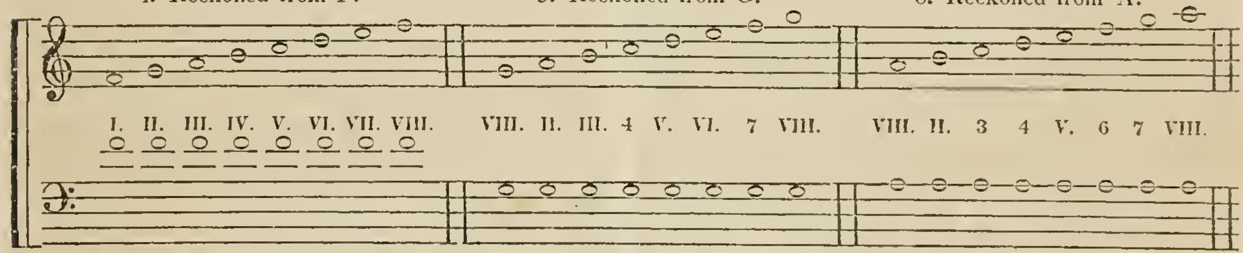
The intervals reckoned from A, are similar to those counted from D, except the sixth, which is minor.

78. Lastly, reckoning from B, we find all the intervals like those reckoned from E, except the fifth, BF, which consists of two tones and two semitones. It is called a minor fifth; and the other fifth found in the other countings, is called a major fifth. Thus we have major and minor seconds, major and minor thirds, major and minor fourths, major and minor fifths, major and minor sixths, major and minor sevenths. All these intervals have remarkably different effects; whether the extreme sounds be played or sung in succession, or struck together. As it is of the greatest importance that the student should understand these distinctions well, and where the major and minor intervals lie within the scale, they are exhibited in notes in the following tables.

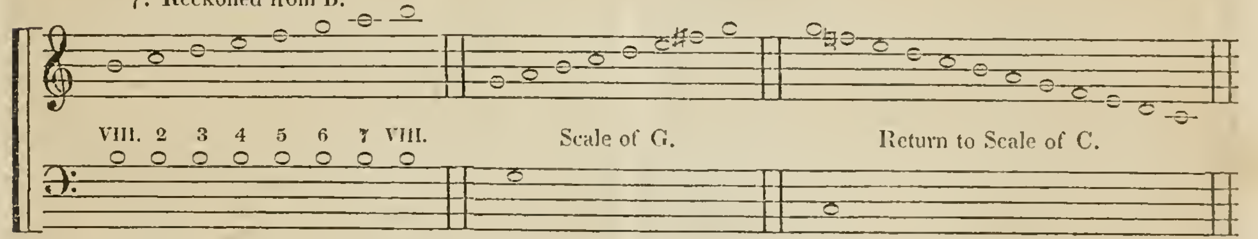
1. Intervals reckoned from C. 2. Reckoned from D. 3. Reckoned from E.



4. Reckoned from F. 5. Reckoned from G. 6. Reckoned from A.


I. II. III. IV. V. VI. VII. VIII.
VIII. II. III. 4 V. VI. 7 VIII.
VIII. II. 3 4 V. 6 7 VIII.

7. Reckoned from B.



In these tables, the major intervals are denoted by the Roman numerals II, III, IV, &c.; and the minor intervals by the Arabic figures 2, 3, 4, &c. But the reader is not to understand that this manner of figuring is used in denoting the accompaniments to be played along with a figured bass. The figure 1, in the three first tables, signifies the unison, which is not properly an *interval*, even when sounded by different instruments. In the fourth and succeeding tables, the bass is removed an octave lower, and then we begin with a real interval, the octave denoted by VIII; the other intervals, though enlarged by octave, are still called seconds, thirds, &c.; and are here denoted accordingly, as if reckoned from a bass note octave higher.

79. These tables furnish some important remarks: 1. They show what is called the *inversion* of all the intervals. To invert an interval, is to place the lower note an octave higher, so that it becomes the more acute of the two, or *vice versa*, in consequence of which the interval between the sounds becomes very different. Thus the interval CD is a major second; but if we invert it, by making D the bass, and C (in the octave above) the higher, we have a minor seventh; and it is plain, that any interval and its inversion complete the octave. They are, therefore, called complements to each other. Hence, the smaller any interval is, the greater is the inverted interval, and *vice versa*. Thus

a minor second,	by inversion, becomes	a major seventh
a major seventh	- - - - - - - - - - - -	a minor second
a major second	- - - - - - - - - - - -	a minor seventh
a minor seventh	- - - - - - - - - - - -	a major second
a minor third	- - - - - - - - - - - -	a major sixth
a major sixth	- - - - - - - - - - - -	a minor third
a major third	- - - - - - - - - - - -	a minor sixth
a minor sixth	- - - - - - - - - - - -	a major third
a minor fourth	- - - - - - - - - - - -	a major fifth
a major fifth	- - - - - - - - - - - -	a minor fourth
a major fourth	- - - - - - - - - - - -	a minor fifth
a minor fifth	- - - - - - - - - - - -	a major fourth.

Hence, to rise by one of the intervals united by the brackets, and to fall with the other, brings us to a note of the same name, but distant by octave. Thus, to rise from C, a major seventh, brings us to B; and to descend from C, a minor second, brings us to B octave below the former. The reader may be surprised that 7 and 2 added, should make 8, and not 9. The reason is, that in reckoning each interval, both sounds are included; and so in the two reckonings one of the notes is twice named, which is only reckoned once when the whole aggregate is reckoned. Thus, we say CD 2, DC 7, and the two intervals added make 8; because counting from C to C, D is only once named among the eight sounds; and this will be found universally the case in adding musical intervals together, as we shall have occasion to see in the sequel. 2ndly, Within the diatonic scale, (extended through two octaves,) we have five major seconds, CD, DE, FG, GA, AB, which, by inversion, become five minor sevenths: two minor seconds, EF, BC, which give, by inversion, two major sevenths; three major thirds, CE, FA, GB, which, inverted, become three minor sixths; four minor thirds, DF, EG, AC, BD, by inversion, four major sixths; six minor fourths, CF, DG, EA, GC, AD, BE, which, inverted, give six major fifths. Lastly, one major fourth, FB, by inversion, a minor fifth. These ought to be studied till they become quite familiar. 3dly, We observe that in all these successive reckonings, the order of the sounds does not in any one exactly correspond with the scale of C; nor are any two of them exactly similar. The order of sounds ascending from G, and that from F bear the nearest resemblance to the scale of C, each differing from it only by one interval.

80. When an octave in the scale is performed either upwards or downwards, beginning and ending with C, it is extremely pleasing and satisfactory to the ear; but if we begin and end on any other note of the scale, we experience a sensible disappointment, especially in ascending. Experience has indeed proved that the order of sounds in the scale of C, is the best adapted for furnishing good music, of which the reader will be more able to judge, when he becomes acquainted with the nature of harmony. But if we could find this order only at one pitch, music would necessarily become monotonous. It is therefore very desirable to have the same order of sounds when we begin with other notes besides C. Now when we compare the series of sounds beginning with G, as shown No. 5, we find the steps exactly similar to the scale of C, till we come to E inclusive, the sixth from G; but we find the interval of minor third between E and G, the octave, filled up in a different manner. In the scale of C, we go from A to B by the degree of a tone, and thence to C by semitone; whereas from E we go to F by semitone, and thence to G by a tone. And this seemingly slight difference would make a wonderful defect in the scale of G. To remedy this defect, a new sound is introduced, which in the piano-forte is given by the short black finger-key between F and G. This new sound is only semitone below G, or major seventh to the octave below, and, consequently, a tone above E. In performing the scale of G, therefore, F is left out; and this new sound played instead of it, and then the scale of G is exactly like that of C. Instead of calling this new sound by an additional letter to the seven used in the scale of C, we call it F sharp; and this introduces a new character into our notation, viz. ♯, which, being placed before any note, signifies that such note is to be taken semitone higher than in the scale of C. When a piece of music is composed in the scale of G, this mark ♯ is placed at the beginning of the staff, on the line or space on which F is placed, immediately after the clef; and this mark at the clef signifies that all the F's throughout the piece are to be performed sharp, unless the composer directs it otherwise. And this calls for a new mark to enable the composer to do so. This character is called a natural, and is written thus, ♮. It signifies that the note before which it is placed, is to be played as in the scale of C.

81. As the scale of G is, by means of F♯, made similar to that of C, it is plain that in making a new scale of its fifth, D, we shall find the same defect in its seventh note. C, which is the fourth in the scale of G, is too flat; it is a minor seventh to D, or a whole tone below the octave d; whereas it ought to be a major seventh to D, or a semitone below d. The same character ♯ put before C, raises it a semitone, which is found in the short black finger-key, between C and D. And music written on the scale of D, has therefore the character ♯ placed both on the line or space of F, and on the line or space of G.

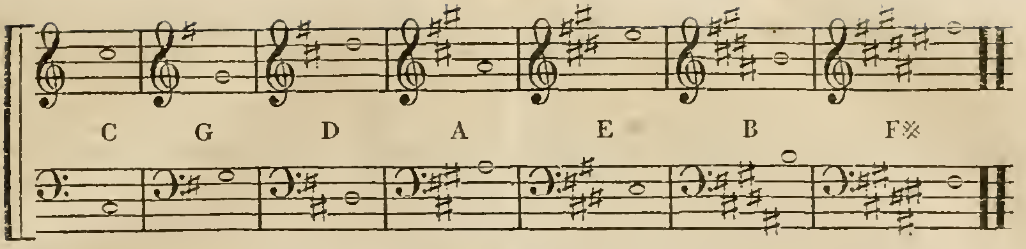
82. It is plain that if we reverse this process, and go from a scale with one or more sharps at the clef to the fifth below, or, which is the same thing, to its fourth upwards, we shall find the note which was major seventh in the former, too sharp for the scale of the latter; it is major fourth, whereas the diatonic series requires minor fourth. We are therefore obliged to remove the sharp from the seventh. Thus, going from the scale of D, with F♯ and C♯, to that of G its fourth, (or fifth counted downwards,) we must remove the sharp from C, in order to have a proper minor fourth in the scale of G. After the same manner, going from the scale of G with F♯ to that of C, its fifth counted downwards, or its fourth upwards, we must remove the sharp from F, when we shall have our original scale C. See this represented in notes at the end of the tables, art. 78.

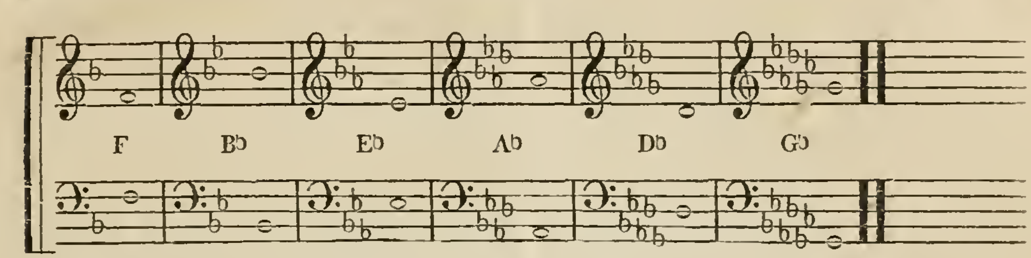
83. Now, should we go from the scale of C to that of F, its fourth (or fifth counted downwards) we should find B, the major seventh to C, too sharp, that is major fourth to F. But here we have no sharp to remove. Another character therefore is used, called a flat, and written thus ♭; which, being put before a note, signifies that it is to be taken semitone lower than in the scale of C. This mark being set before B, signifies that it is to be played on the short black finger-key, between B and A, which being semitone flatter than B, is thus minor fourth to F. And music written in the key of F, has a flat put at the clef, on the line or space of the note B, which signifies that throughout the piece every B is to be played flat, unless otherwise signified by the musician. But to do so, he has no need of a new character; the ♮ natural set before a flattened note, signifies that it is to be played as in the key of C.

84. It is plain that, for the same reasons, if we go from the scale of F to that of B, its fourth (or fifth downwards) it will be necessary to flatten the E, major seventh to F, and major fourth to B♭, in order to have a minor fourth for the new scale. And it is equally plain, that if we reverse this process, and go from a scale with two or more flats, to the scale of its fifth above, we shall be obliged to remove the ♭ from the note which was minor fourth in the former, and which is now to be major seventh in the latter; and by repeating this process, we shall at last come to C again, which has neither sharp nor flat in its scale.

85. It is for this reason that music written in the scale of C, is called natural; not that it is more *natural* to have the diatonic series of sounds at one pitch than at another, or that music written in scales with many flats or sharps, is more *artificial* than the other. It is true, indeed, that in general music written on scales requiring many sharps or flats, is more difficult of execution; but this arises solely from the construction of instruments, and is altogether unconnected with the nature of the music itself.

86. The reader is now possessed of a general rule, capable of very easy application, by which he may find the number of flats or sharps to be placed at the clef of any scale, or of any *key*, as musicians say; and also to find where these sharps or flats are to be placed in the major mode. We shall therefore here exhibit this notation in the G and F clefs, with a remark or two, in which the reader is prepared to go along with us.

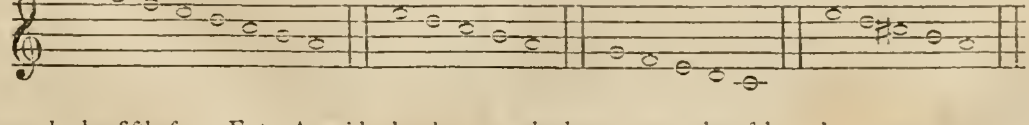




As in adding sharps to the clef, we follow a series of ascending fifths or descending fourths, and as the sharp is always to be put in the same place of the scale, it is plain that the notes to be sharpened will be found by the same rule, that is, by counting five degrees upward, or four downward, from the last added sharp; therefore they will observe the following order, F♯, C♯, G♯, D♯, A♯, E♯. After the same manner, as in adding flats at the clef, we follow the inverse order, that is, a series of fourths upward, or fifths downward, the order of flattened notes will be found to be B♭, E♭, A♭, D♭, G♭, C♭.

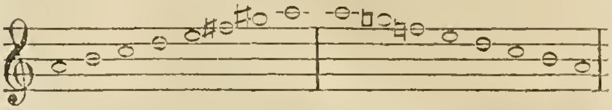
87. It may now be natural to ask, where these sounds are to be found in keyed instruments; for it is evident we have now a much greater number of notes, than there are finger-keys in any octave of the instrument. We have already noticed the two short finger-keys, F♯, C♯, and the two short finger-keys B♭, E♭. Now if we go a step farther in the addition of sharps and flats, we shall find that the next sharp and the next flat meet on the same finger-key. For in the scale of A we must have G♯ a semitone below A; and in the scale of E♭ we must have A♭, also a semitone below A. On keyed instruments in general, there is but one sound to answer for both. It is proper here to apprise the reader, that this is a great imperfection; and on instruments which are capable of being played perfectly in tune, the difference between these two sounds is very considerable. To give the reader some idea, in passing, of this matter, which will be fully explained in the sequel, let the major third, CE, be tuned quite exact, and another third, EG♯, be also tuned quite exact, then the G♯ will be quite true as major seventh to A, the major sixth in the scale of C. Again, if A♭ be tuned a major third below C, it will then be true as fourth in the scale of E♭, the minor third to C. If now these two sounds, G♯ and A♭ be compared, they will be found to differ very sensibly. The difference is about the fourth part of a tone, and it is called the enharmonic fourth of a tone, or the enharmonic diesis. From this the reader will be sensible, that keyed instruments, in general, are not tuned to the most perfect intervals; but this matter we must not enter on at present. In the mean time we see that each of the black finger-keys, and even some of the long finger-keys, have two names, and answer for two sounds; thus D♯ and E♭ belong to the same finger-key, as do also A♯ and B♭; and in the scale of F♯ we have E♯ semitone sharper than E, which therefore comes to be the same finger-key with F. So also following the additional flats after A♭, we have D♭ and C♯, G♭ and F♯, C♭ and B. And when we come to the last of each series here set down, viz. F♯ with six sharps at the clef, and G♭ with six flats, the two scales are exactly the same throughout; insomuch, as far as regards keyed instruments, that it is a matter of indifference in which way the music for that scale be written. But the reader will easily see that it is of much importance to preserve the distinction between A♯ and B♭, &c. even in composing for keyed instruments. Inextricable confusion would indeed result from a contrary practice. These remarks are the more necessary, that some persons, deceived by the identity of the sounds on keyed instruments, have concluded that there is no such distinction among musical sounds; and it is sometimes very difficult to make them comprehend that there is such a thing. We shall afterwards find that even these sharps and flats are not sufficient for all the purposes of the musician, insomuch that double flats and sharps frequently occur, thus denoted ♭♭ and ×. So × put before the note F♯, signifies that it is to be taken a semitone still higher, which on keyed instruments is the same with G. ♭♭ set before B♭, makes it a semitone lower, played by the finger-key of A.

88. That we may give the whole doctrine of the flats and sharps to be placed at the clef at once, we must now make the reader acquainted with another scale of musical sounds, called the minor diatonic scale. If in the natural scale, (that is, the scale of C) we take an octave of notes from A upwards, we find a scale of a very different character from that of C. If this scale be played descending, we find it not only very agreeable, but also that we come to a satisfactory conclusion on A. By comparing the descent through the fifth from E to A, with the descent through the fifth from G to C, we shall be sensible of a very different effect. The former is a wailing plaintive song, and the latter more cheerful, and we may say more bold and masculine. This difference arises not from the pitch of the two songs, but from the nature of the last thirds of either



descent; from C to A being a minor third, and from E to C being a major third. If the reader wish to compare these two songs at the same pitch, he has only to play C natural and C※ alternately descending from E: but he will find the transition from the one to the other, especially from the series with minor third to that with major third, more harsh than in the former comparison. It is from these thirds principally that the two scales are named, and that music drawn from the one or other is said to be in the major or minor mode. But the minor sixth AF is also an important interval in this scale, and contributes to its peculiar effect, of which the reader may easily satisfy himself by comparing the descent through an octave from d to D, with that from a to A, or by playing F※ in descending through the octave of A, while the other notes remain as in the natural scale.

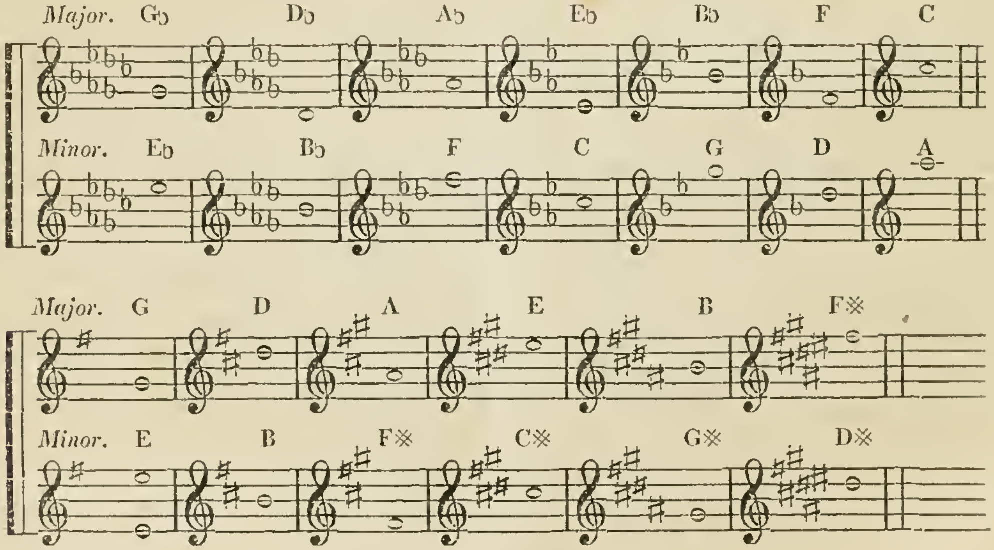
89. In ascending though this scale of A minor, we find the progression very agreeable; yet we are sensible that in coming to the octave a by the degree of tone from G, there is the same defect that we formerly noticed in the series from G to g in the natural scale: The conclusion is not so complete and satisfactory as we wish. Hence the necessity of having G※ a semitone below A, to bring us to a conclusion on the key-note, as musicians speak. The reader, however, will be still more satisfied of the necessity of a major seventh in the minor scale. when we come to speak of the nature of harmony. Now, if in the ascending scale of A minor, we make the G sharp, we find in the step from F to G※ a species of interval very different from the other degrees of the diatonic scales. Hence arises a kind of necessity of giving the minor scale a major sixth F※ also: not that the interval from F to G※ is, as some respectable authors say, *a false relation:* We shall afterwards find that it is a true musical relation, and used with excellent effect; but it is not as we have said, a *diatonic* degree. Hence it is that the minor scale is usually written in a different manner, ascending and descending, thus:



The reader, however, is not to suppose that the sixth and seventh are always major in ascending, and always minor in descending.

90. The minor mode of A is called the *relative minor* to C major; and the latter is called the *relative major* to the former. And thus to every major scale, the *key-note* of the relative minor is the major sixth above, or minor third below, and *vice versa*, to every minor scale the relative major is on the minor third above, or major sixth below. Now these two relatives have always the same number of sharps or flats at the clef, or the *same signature*, as it is called: and when in the minor mode the sixth or seventh is to be sharpened, this is signified by a ※ placed before the note in the course of the piece. Sharps or flats not placed at the clef, but occurring in the course of the piece, are called *accidental flats* or *sharps*.

Thus then C major and A minor have neither sharp nor flat at the clef: G major and E minor have F※; D major and B minor have F※ and C※, &c. But this will be more clearly exhibited in the following table: in which, beginning with six flats, and proceeding by fifths upwards, or fourths downwards, these relatives are set down together.



91. From this table the reader may observe that the difference of signature between the major and minor modes of any one note is always three sharps more, or three flats fewer in the major mode than in the minor, or what is equivalent to the difference of three sharps or flats. Thus C major is natural; C minor has the signature of three flats; A major has three sharps; A minor, natural; D major has two sharps; D minor has one flat, equivalent to three sharps more, or three flats fewer, in the major than in the minor mode of D: G major has one sharp; G minor has two flats, equivalent to the difference of three sharps, or three flats. So that (considering the table as one continued line) the minor mode of any note will be found in the table three steps toward the left hand, and *vice versa*.

92. It is proper to observe that in old music, such as that of Corelli, and even not unfrequently of Handel, in the signature of the minor mode with flats, the last flat is omitted at the clef, and is therefore inserted in the course of the music as an accidental. Thus D minor is found without a flat at the clef; G minor with one flat; C minor with two flats, &c. This has probably arisen from the major sixth of the scale being occasionally used in the minor mode, as already observed. But it is more difficult to account for the omission of the last sharp, in the signature of the major

mode, of which instances occur, as two sharps in the key of A major, three sharps in that of E major, &c. It is hardly necessary to observe, that in such instances, the last sharp must appear as an accidental for the major-seventh of the scale.

93. If all the notes thus added to the scale, in order to obtain a diatonic series for each note of the key-board, be arranged in order as they become gradually more and more acute from any note, C for instance, they produce what is called the *chromatic scale*. This name is derived from a Greek word which signifies *colour*, and it is applied to music in a metaphorical sense, meaning that the most finished and ornamented style of music is furnished by this scale. It is a term borrowed from the sister art of painting. Mere diatonic music may be not unaptly compared to *design*, in which light and shade, without colour, are employed; and chromatic music to *painting*, properly so called, in which the artist adds all the beauties of colours. Without seeking to pursue this analogy too far, it is quite true that the chromatic scale adds as much to the resources of the musician, as colours do to those of his brother artist. Many new intervals, besides those which have already been described, arise out of this scale, with which the student will afterwards be made acquainted. But it is proper we should now proceed to explain the use of those arising out of the diatonic scale: viz. seconds, thirds, fourths, fifths, sixths, and sevenths, major and minor, together with the octave and unison. For though this last be not properly an interval, the use of it is regulated by precepts as strict as that of any interval properly so called.

CHAP. II.

OF THE MOVEMENT OF CONCORDS; OF COMMON CHORDS, THEIR SPECIES, POSITIONS, AND PROGRESSIONS; OF THE DERIVATIVES OF COMMON CHORDS, AND THEIR PROGRESSIONS.

94. A succession of single musical sounds, duly ordered in respect of the intervals, forms *melody* or song. Two or more musical sounds, differing by proper intervals, heard at the same time, form a *chord;* and a proper succession of chords forms *harmony*. The union of melody and harmony forms the best music. These two branches of the musical art must be considered separately, to a certain extent; but neither can be thoroughly understood without a knowledge of the other. Of these two branches, harmony is capable of more precise rules than the other. We shall therefore endeavour to make the student acquainted with the most simple, and at the same time the most important of these, before we attempt to investigate the nature of melody.

95. Musical intervals are either concords or discords. The octave, the major fifth, the major and minor thirds, the major and minor sixths, are concords, and are pleasing in themselves. The seconds, major and minor, the sevenths, major and minor, the minor fifth and major fourth, are discords; they are not so pleasing in themselves, but they are much used in harmony, and greatly heighten its effects. It has been much disputed whether the minor fourth (the inversion of the major fifth) ought to be ranked among the concords or among the discords. There can be no doubt that in many combinations it is truly concordant. On the other hand, in some situations and combinations, it is felt to be a discord, and treated accordingly: but this the student will understand better bye and bye.

The unison is the most perfect relation that subsists among musical sounds, and it may, without impropriety, be called a perfect consonance or concord. The octave is next after the unison, the most perfect concord, and the major fifth the next in point of perfection; it is therefore usually called the *perfect fifth*, which name, as being familiar with musicians, we shall generally use hereafter. The minor fifth, in contradistinction, is usually called the *imperfect fifth*, or *dissonant fifth*, or *false fifth;* and these expressions we shall also use as synonymous.

97. The unison, the octave, and the perfect fifth, are called perfect concords. Thirds and sixths, major and minor, are called imperfect concords. It is necessary to keep this distinction in mind, in order to understand the rules laid down for the succession of intervals between two parts.

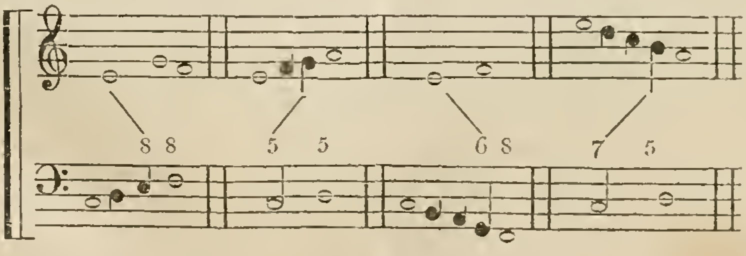
98. These general rules we shall give immediately; but it is necessary first to explain the different kinds of motion. When two parts both ascend, or both descend at the same time, they are said to go in *similar motion*. When one part remains at the same pitch, while the other ascends or descends, the motion is called *oblique*. When one part ascends, and the other descends, the motion is called *contrary*.

99. The first rule for the movement of concords is, that there must not be two perfect concords in succession, between the same parts, by similar motion. These are technically termed, consecutive octaves: and octaves in succession are forbidden, because they produce no good effect, and fifths, because they produce a very bad one.

N. B. This rule does not respect two or more instruments or voices, moving together in unison or octaves, in the same melody, which is called doubling the part, and is universally practised.

The second rule is, that you must not go from an imperfect concord, to a perfect concord, by similar motion. These passages are said to contain *hidden* octaves or fifths, which are made apparent by filling up the diatonic degrees through which one of the parts is conceived to pass; which cannot take place when the parts move in contrary directions, as is shown by these examples.

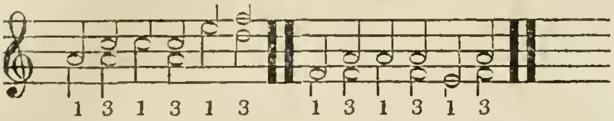
Similar Motion. Contrary Motion.



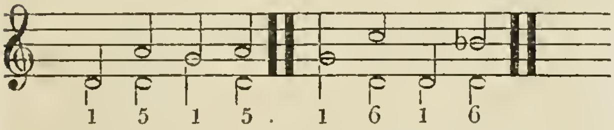
100. These rules will be fully illustrated in the sequel. In the mean time we shall quote from Mr. Shield's excellent Introduction to Harmony, his directions for the management of the unison, and of the fifth. "When both parts move, it is better to go from the unison to the third minor, than to go to the major. To the minor we may go either by oblique, or by contrary motion; Ex. 1st. But to the major we must, by oblique, or by similar motion: the first is the best; Ex 2d.

We must avoid a fifth, after a unison, by similar motion. It is good in oblique motion, and is allowed in contrary motion, one part moving a single degree; Ex. 3d. From the unison we may go to the sixth minor, by contrary motion. It is not very good by the other motions, because of the large leap; Ex. 4th. But it is forbid to go from the unison, to the sixth major. We must avoid an octave after the unison, except by oblique motion: for this, as in two unisons, is but as the division of a large note into smaller."

Ex. 1. Minor Thirds. Ex. 2. Major Thirds.

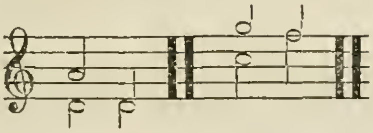


Ex. 3. Fifth. Ex. 4. Minor Sixth.



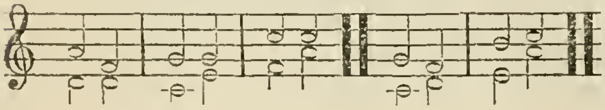
These rules for the unison, Mr. Shield gives from Dr. Pepusch, " whose treatise," he observes, " is dated in 1731; consequently contains many exploded doctrines; but it likewise contains principles which will be the basis of theory in 1800, or any other century."

The following law respecting fifths, Mr. Shield says, was laid down by an excellent judge, and has been so much respected, as to be generally obeyed by correct writers, for more than half a century. " From the fifth to the unison is good, by oblique motion; we may also go by contrary motion, one part moving a single degree; but it is bad by similar motion.

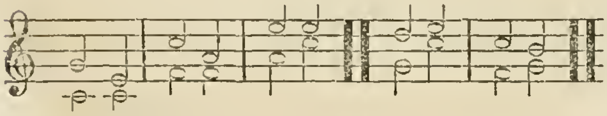


From a fifth we may go to either third, by all the motions, but best by the oblique. The next best way to the third minor, is by contrary motion, and to the third major is by the similar; both these by single degrees.

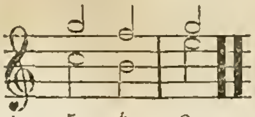
From Fifth to Third Minor.



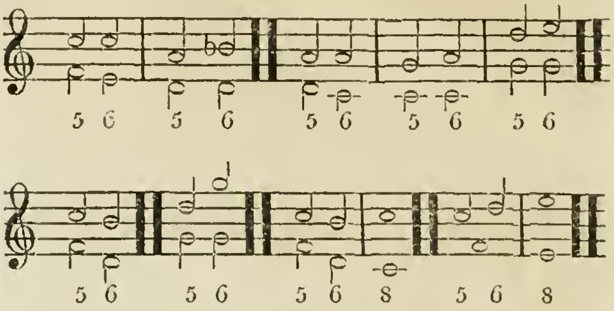
To Third Major.



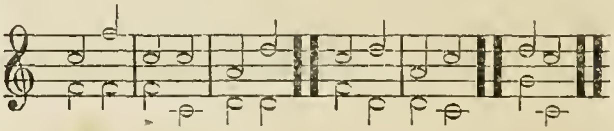
A false fifth or *semidiapente*, may immediately follow a perfect fifth, provided it be also immediately succeeded by a third gradually, and by contrary motion.



From the fifth to either sixth, is best by oblique motion; it is also allowed by similar motion, one part moving a single degree; and it is allowed ascending, but not descending, to go by a leap from the fifth to the sixth minor, but not to the major. In passing from the fifth, through the sixth, to the octave, the sixth must be major, never minor, and that by contrary motion.



We must avoid an octave after a fifth by leap, in similar motion. It is good by oblique and contrary motion, and may be allowed in similar motion, one part moving a single degree."

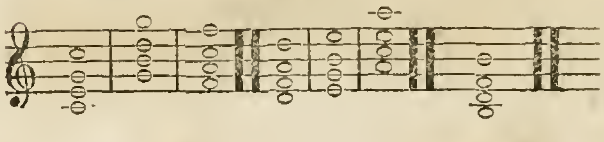


This last example, we may add, in which the octave follows the fifth descending, the upper part falling a tone, is quite classical, and universally practised.

101. We now proceed to consider the combinations of intervals in chords, and the manner in which chords may succeed each other. When a note is sounded along with its third and fifth, with or without the octave, the combination is called a *common chord*. The Germans call it a *triad*, which name is adopted also by Dr. Callcott, in his Musical Grammar. Common chords are distinguished into major and minor, according as the third is major or minor. The difference in the effects of these two kinds of chords is very striking. The distinction is one of the most important in music, and is what chiefly constitutes the major and minor modes, as already observed.

102. From the tables of the major and minor intervals in the diatonic scale, given in art. 78, it is easy to see what common chords are major, and what are minor. In the major mode, the common chord to the lowest note of the scale, which is called the key-note, the chord of the fifth of the scale, and that of the fourth of the scale, are major. The chords of the second of the scale, of the third, and of the sixth of the scale, are minor. The chord formed by the seventh of the scale, with its third and fifth, differs from all these, as the fifth is imperfect, which is a discord. This is therefore called the imperfect, or dissonant common chord. These we exhibit in the major mode of C, leaving it to the industry of the student, to write them in other *keys* or scales.

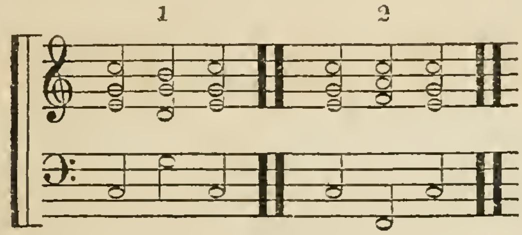
Major. Minor. Imperfect.



All these chords are occasionally used in a piece of harmony in the major mode, but they are by no means all of equal importance, or of equally frequent use.

103. The most important of all these chords is that of the *key;* it is called the harmony of the key, or the *tonic* harmony; with this harmony, every regular piece of music in the major mode begins and ends. All the other chords must proceed regularly from this, and return to it in such a manner as to heighten its effects.

104. The next chord in point of importance and frequency, is that of the fifth of the scale. These two chords succeed each other in a very agreeable and natural manner, whether we go from the chord of the key to that of its fifth, or in the inverse order; Ex. 1.



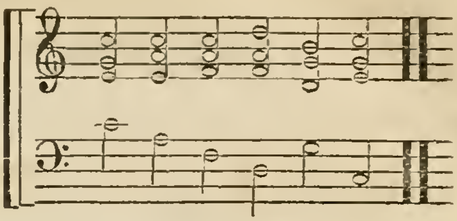
The last of these two progressions, namely, from the harmony of the fifth of the key to that of the key itself, is almost always the concluding progression in any piece of music. It is called the *perfect cadence*, or close, and is the most conclusive and satisfactory progression in harmony; but how much *accent* and *rhythm* contribute to this conclusive effect, will be seen afterwards.

From this effect, the harmony of the fifth of the key is called the *leading chord;* and it is also called the *dominant* chord, because it governs or requires the tonic harmony to succeed it.

In this cadence, the major third of the leading chord (the major seventh of the scale) must ascend by semitone to the octave of the key-note; and this major third of the dominant is called the *sensible* note, or the *leading* note to the key.

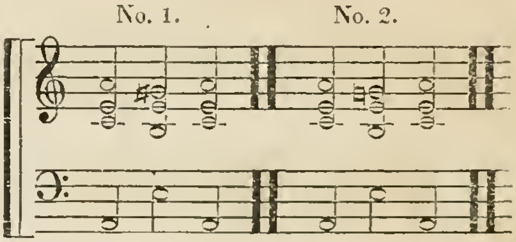
105. The next chord in importance after these two, is the chord of the fourth of the key. This harmony, and that of the tonic also, succeed each other in a very agreeable manner, (see Ex. 2. above, art. 104,) and the progression of the chord of the fourth of the scale to that of the key-note, (assisted by accent and rhythm,) forms another kind of cadence or close of a satisfactory nature, though not so conclusive as the perfect cadence; it is called the imperfect cadence; hence this chord is called the *subdominant* chord. These three chords comprehend, as Dr. Callcott observes, all the notes of the diatonic scale. In the tonic harmony are found the key-note, 3d and 5th; in the subdominant, the 4th and 6th; and in the dominant, the 2d and 7th. "These three principal sounds," he observes, "the *Tonic, Dominant,* and *Subdominant,* are the radical parts of every scale, of the minor as well as of the major. All melodies whatever, are derived from these sounds, and are wholly dependent on them." He adds, in another place, "the following excellent observations of Dr. Pepusch, cannot be too often or too strongly impressed upon the mind of the student, viz. *All melodies have the perfect concords of the key they are in,* (i. e. the tonic, dominant, and subdominant,) *for their fundamental basses.*" By these observations, the student may judge of the importance of these three harmonies: the matter is, however, too broadly stated; for, as we have already said, every common chord in the scale is occasionally employed.

106. The next chord to these in importance, and frequency of use, is that of the sixth or relative minor, and then the common chord of the second of the scale, which is the subdominant of the relative minor, and is itself minor. These five harmonies are exhibited in the next example.

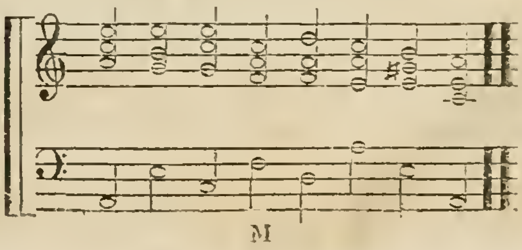


The student will not often find a series of so many mere common chords in modern compositions; but he will find that these harmonies, somewhat differently arranged or *inverted*, and with some additions, which produce *discords*, constitute the principal part of harmonical progressions or modulations, while these continue within the key; and when the modulation passes into another key, he will find the harmonies similarly related to that new key.

107. After the same manner, in the minor mode, the most important chord is that of the key, and the next is the *dominant* chord on the fifth of the key. The student must observe that this chord has a major third, which is essential to its character of dominant, that is to say, to its making a satisfactory close on the key. Of this, the reader may soon satisfy himself, by comparing Nos. 1st and 2d in the next example.



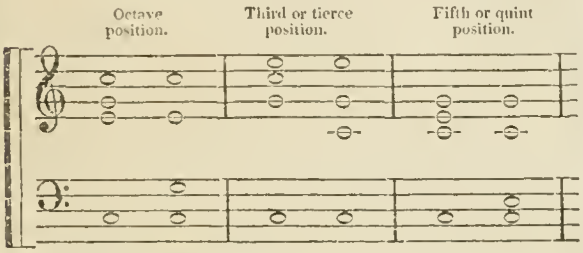
One often hears the progression No. 2d in the psalmody of country churches. This, and the universal practice in the early ages of music, seems to countenance the theory that the minor mode is a secondary key to its relative major, the impression of whose scale is never entirely effaced from the ear. However this may be, the fifth of the minor mode may bear a minor chord, but then it loses entirely the character of a dominant chord. The next chord in point of importance is that of the subdominant; after that the relative major, and its subdominant chord, which is that of the sixth in the minor scale. These two last chords seem even more welcome in a modulation in the minor scale, than the relative minor and its subdominant in a modulation in the major scale. These chords are exhibited in the next example.



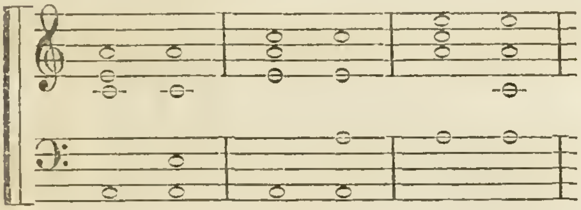
In the above example, the subdominant chord is minor; but it has not unfrequently a major third given it, as we shall see afterwards.

108. The lowest note of a chord is called its *bass*, and the lowest note of a common chord is called its *fundamental bass;* and a common chord itself is called a fundamental chord, in order to distinguish it from the chords that arise from its *inversions;* these will be explained bye and bye. In the mean time, we shall exhibit the common chord in different *positions*. Besides the bass, a common chord has two sounds, the third and fifth; and if the octave to the bass be added, there are three sounds in the upper parts. Now, these three upper parts may be arranged in various *positions*, which musicians distinguish into three, according as the octave, third, or fifth, hold the uppermost part. But of the four sounds, the bass and uppermost parts being determined, the two remaining sounds may be varied in two ways, which give two forms to each of these positions, thus:

Major Chord.



Minor Chord.



These two different forms of each position make the distinction between *close* and *dispersed* harmony. Yet on comparing them, the student will find that the effect of the uppermost sound is so decided, that there is as much propriety in calling the two forms of each the same position, as there is in calling them all the common chord, because the fundamental bass remains. And this remarkable effect of the bass and highest part is always observable; therefore the right ordering of these two parts is to be most carefully attended to. They are called the *extreme parts*, and the others are called the *middle* parts, or inner parts.

The position in which the octave is the highest sound, is the most satisfactory of the three; and hence this position is generally preferred at the close of a strain or piece of music. That in which the third is highest, is also satisfactory, and therefore may be the concluding form of the chord. But that in which the fifth is highest, does not completely satisfy the ear; it rather leads to the expectation of something to follow. Hence it is very proper in the beginning, or in the less formal closes in the middle of a strain, or at the end of a first strain, when another is to follow; but it is very seldom found at the final close.

109. The examples which we have hitherto given, are in four parts. In compositions of more than four parts, it is plain that some of the parts must be *doubled*, *i. e.* the same note given to two or more parts, either in unison or octave. The general rule is, that the fundamental note should be first doubled, then the fifth, and last the third. But this rule is still subservient to that which forbids consecutive perfect concords between the same parts, and to the propriety of giving as good a melody to all the parts as possible.

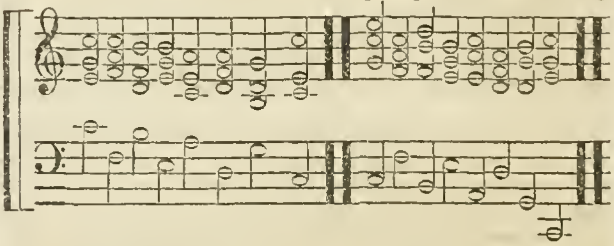
When the dominant chord is to make a cadence on the chord of the key, its third ought not to be doubled, because as that third must rise to the key-note, two parts would then be obliged to move in octaves or unisons.

In compositions of fewer parts than four, the octave or fifth are to be omitted rather than the third, because this determines the species of the chord as major or minor.

110. Common chords succeed each other most agreeably, when the two chords have one or more sounds common to both; and this will be the case when the bass rises or falls by a fourth or by a third, as in the following examples:

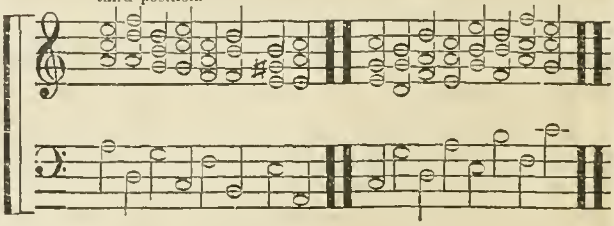
1. Falling 5ths and rising 4ths.

2. The same in another position, beginning with the bass ascending.



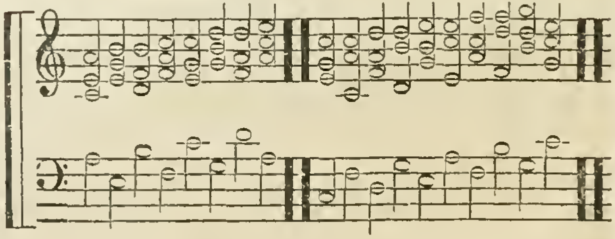
3. The same in Minor, in a third position.

4. Rising 5ths and falling 4ths.



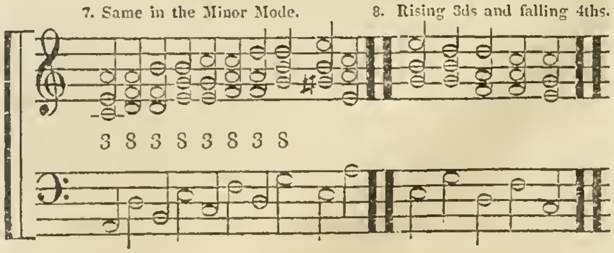
5. Ditto Minor, beginning with the descent.

6. Rising 4ths and falling 3ds.



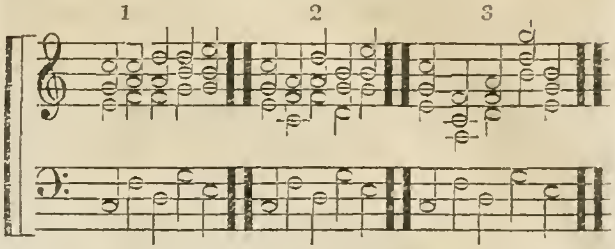
7. Same in the Minor Mode.

8. Rising 3ds and falling 4ths.



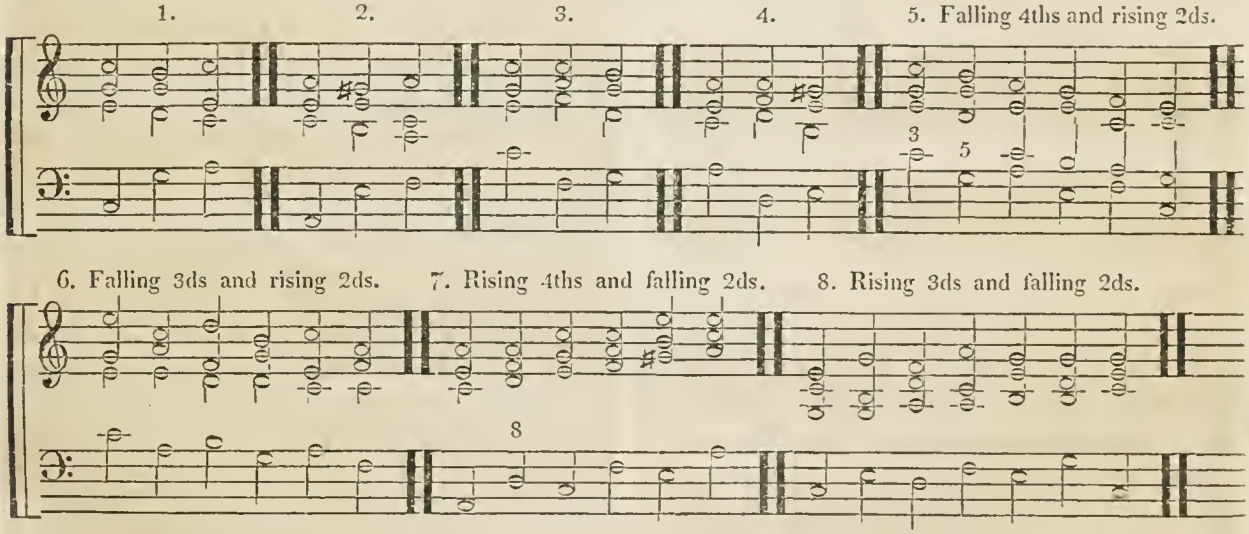
The student will observe, that in these examples, the imperfect chord on the seventh of the major scale, and second of the minor, is treated in the same way as the consonant common chords. On this account, some have even gone so far as to call this a consonant chord. But this is an abuse of language. The ear is reconciled to this free use of the imperfect chord, in such progressions, by the orderly succession of the chords. But the chord in question is truly a discord, and as such, generally receives that particular treatment which will be explained afterwards. The student will find a profitable exercise in writing and performing these progressions in different keys. He should write them in different positions, and varying the manner of beginning the progressions. Let him be very careful to avoid consecutive perfect concords in similar motion, and also to avoid taking a perfect concord after an imperfect, in similar motion, between the same parts. He will then see the reason why we have given several of these progressions in different ways. No. 7, is taken from Kollmann's New Theory; and the reader will observe, that in every second step, the third proceeds to the octave by similar motion between the bass and third part. Here the procedure is so covered by the higher parts, as to give no offence. Indeed, when the upper part rises a single degree, and the bass rises a fourth, as in this example, the progression is sanctioned by the practice of the best authors. But in his first exercises, the student cannot be too strict in observing these rules. In No. 6, this is avoided by doubling the fifth of the chord rather than taking the octave.

111. The student must also be careful to dispose the several parts in an orderly and melodious manner. This is so well stated and exemplified by Mr. Kollmann, in his New Theory, that we shall copy his explanation and examples. "To connect intervals properly, it is required, either to keep every repetition of a note in its former place, or to change the notes of the different parts in such a manner, that the ear may easily follow the progression of every part.



No. 1. is a progression by fundamental concords, where every repeated note is kept in its former place, and, consequently, this example is most connected. No. 2. is the same progression; but the parts changed in a melodious contrary motion. No. 3. is the same progression, but the parts tumbling about in an unmelodious manner, which is therefore not good."

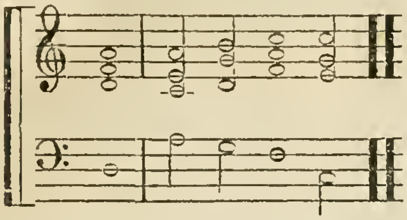
112. One common chord may also succeed another diatonically, that is, by one degree of the diatonic scale; but then the parts must move in opposite directions. This progression often takes place from the dominant of the major mode to the relative minor, or from the dominant of the minor mode to the chord of the sixth of the scale; and these progressions taking place in the proper part of the measure, form what are called interrupted cadences; Nos. 1. and 2. of the examples following. When the subdominant chord rises diatonically to the dominant, it forms what Dr. Callcott names the mixed cadence; Nos. 3. and 4.


1.
2.
3.
4.
5. Falling 4ths and rising 2ds.
3
5
6. Falling 3ds and rising 2ds.
7. Rising 4ths and falling 2ds.
8. Rising 3ds and falling 2ds.
8

Nos. 5, 6, 7, 8, are different progressions produced by the rise or descent of the bass diatonically. In Nos. 5 and 7, we have allowed a third to be followed by a perfect concord in similar motion between the bass and third part, which can hardly give offence, being so well covered by the upper parts. Besides a third followed by a fifth in similar motion, when the upper falls one degree, as in No. 5, is very good, and universally practised even between the extreme parts, or in two parts.

113. M. Rameau, and after him Mr. Kollmann, lay it down absolutely as a rule, that one fundamental concord cannot follow another diatonically. The latter gentleman accounts for such progressions, by saying that one or other of the chords is a discord from which the discord is removed. This is that very convenient kind of reasoning which logicians call begging the question, by which any thing may be made of any thing; of which he is so fond, that he constantly uses it throughout his book. We are content with teaching the procedure as classical, and of good effect, leaving system-makers to account for it as they may. We must however repeat, that chords succeed each other best, when they are connected by some common sound. On this subject we may quote the following observations from Dr. Burney. "In old compositions the harmony of each note in the scale seems detached and unconnected by relative sounds; and in the new, two chords seldom succeed each other, without being combined by some sound, in common with both. The following basses, with no other harmony

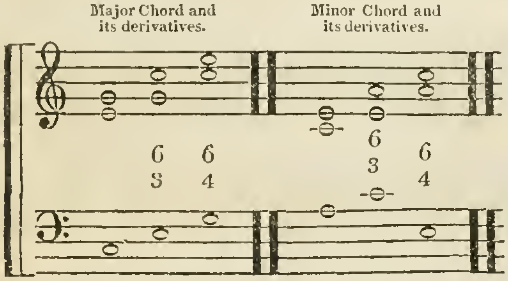
than common chords, perpetually occur in ancient music: DC, CE, EG, AGF. Of this last modulation I can give no better illustration than the following beginning of a chant of Palestrina, from a manuscript chiefly in his own handwriting.



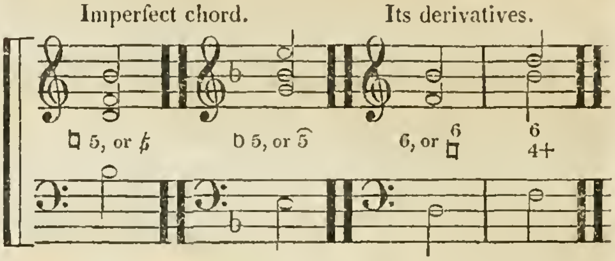
"The old masters," he observes, "often accompanied six of the seven notes in every key with common chords. The moderns, on the contrary, allow them only to the key note, and its fifth; to all the rest they (generally) give a sixth or a discord."

We shall now, therefore, proceed to exhibit the inversions of the common chords.

114. A common chord has only three *real* parts, for the eighth is only a doubling of the bass note. So long as this fundamental note is lowest, however the upper parts may be arranged, the *common* chord remains. But if we set either of the two remaining real parts in the bass, we invert the chord; and thus the common chord has two inversions. From what we have said, art. 79. concerning the inversion of any interval, the reader will easily understand this proceeding. Let us begin with the major chord. If instead of the fundamental note, we put the third of the common chord for bass, placing the fundamental sound an octave higher, that is inverting the interval, we shall have a chord consisting of a minor third and minor sixth. This is called a chord of the sixth, and in thorough bass is figured $^{6}_{3}$, or simply 6, the third to the bass being understood. If again we put the fifth of the common chord for bass, we have a chord consisting of the perfect (or minor) fourth and major sixth; called the chord of the fourth and sixth, and figured thus $^{6}_{4}$. These two chords are called the first and second derivatives of the major common chord.

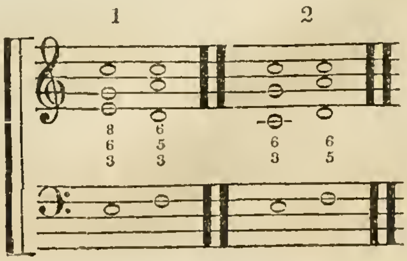

Major Chord and its derivatives.
Minor Chord and its derivatives.
6 3
6 4
6 3
6 4

After the same manner, by inverting the minor chord, we obtain its two derivatives. Its first derivative consists of a major third and major sixth, and in thorough bass is figured $^{6}_{3}$, or simply by 6, the third being understood. The second derivative of the minor chord consists of a perfect fourth and minor sixth, figured also $^{6}_{4}$. Although these derivatives of the major and of the minor chords differ so very essentially in their component parts, and in their effects, no confusion arises to the thorough bass player from their being figured in the same way; because he is to take the intervals indicated by the figures as they are found in the scale in which he is playing at the time as indicated at the clef. When the composer intends any other interval, as when he changes the key, the change is intimated in the figures, which we shall explain more particularly afterwards. Common chords are not figured at all, except on some particular occasions, when it becomes necessary, as shall afterwards be shown. The imperfect chord on the seventh of the major and second of the minor scale, is usually figured with a 5, and generally with some additional indication that the lesser fifth, and not the perfect, is intended, as $\natural$ 5, $\flat$ 5, $\not{5}$ or $\widehat{5}$.

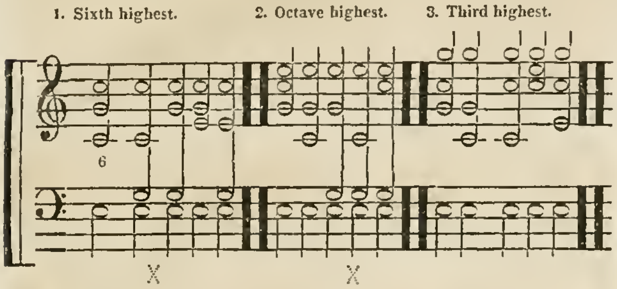


Mr. Kollman would have the last of these used solely to indicate the chord of the lesser fifth, when it is treated after the manner of a consonant common chord, and the other signatures to be employed to indicate the use of it as a discord, as will be explained in the sequel. By inverting this chord, we have two derivatives; 1st, when the third is made bass, a chord consisting of a minor third and a major sixth. This is figured $^{6}_{3}$, or simply by a 6, like the 1st derivatives of perfect common chords major and minor. To prevent ambiguity, a natural may be put under the 6, thus $^{6}_{\natural}$ to indicate that the third is to be taken as in the scale; but this is not usually done. When the fifth of the imperfect chord is put in the bass, we have a chord consisting of a major fourth and a major sixth, figured thus $^{6}_{4+}$ the dash or cross added to the 4, indicating that it is the major and not the perfect fourth. However, we shall have occasion to speak of these chords, and their signatures or figures again, when we treat of the inversion of the seventh.

115. A chord of the sixth, like the common chords from which it is derived, has only three real parts. In compositions of four parts it is more usual to double the sixth (which is the fundamental sound) or the third, (the fifth of the original chord) than to take the octave to the bass. This rule, however, is by no means absolute, as Dr. Callcott might lead the readers of his Musical Grammar to think, except in a particular case, which we shall notice bye and bye. In particular, it must yield to that of avoiding consecutive perfect concords between the same parts, as the following example from Mr. Shield will show.



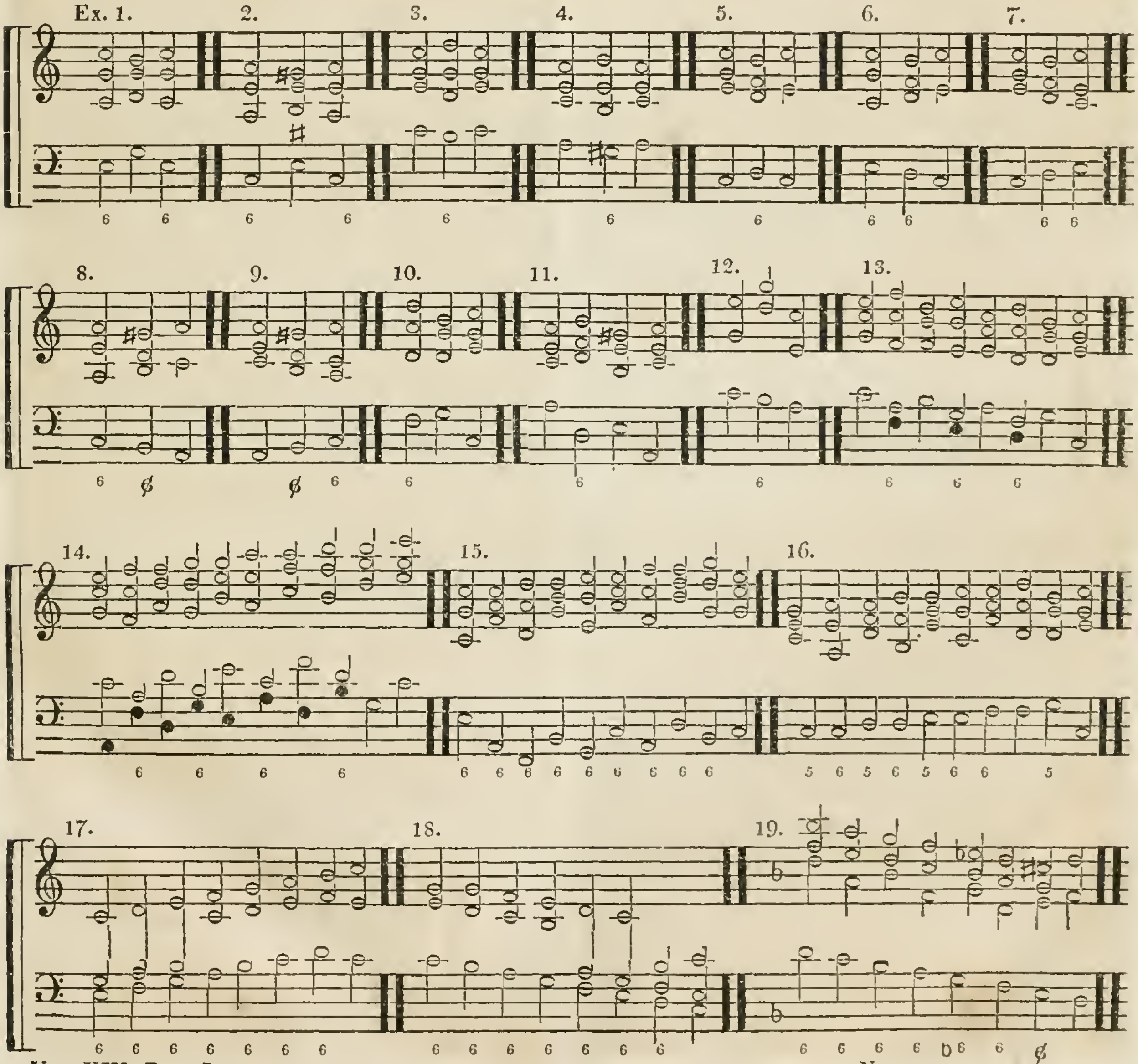
The last chord in each of these examples is a discord, with which our readers have not yet been made acquainted. In the second example, the student will notice the fifths between the second and third parts, which, in the first example are avoided by taking the octave to the bass of the first chord, instead of doubling the sixth. Like the common chord, the chord of the sixth has different positions, and the harmony may be close or dispersed, as in the next examples.

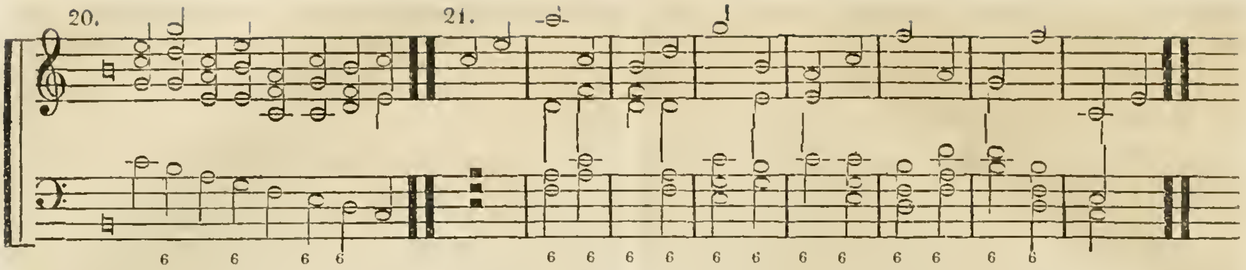


Those positions are the best, in which the harmony is most equally dispersed. Those in which it is very unequally separated, as those marked with a cross, are not so agreeable, though cases will occur in which they may be used.

116. The chord of the sixth on the third of the key, or the first derivative of the tonic harmony, alternates very agreeably with the dominant chord. Ex. 1 and 2.

The chord of the sixth again on the major seventh of the scale or sensible note, which is the first inversion of the dominant chord, alternates very naturally with the common chord of the key, Nos. 3 and 4. The latter of these progressions, viz. from the first inversion of the dominant to the chord of the key, when it takes place on the proper part of the measure, forms an inverted cadence, by which musical phrases are frequently terminated in the middle of a strain. This is the case in which the octave to the bass of the 6th ought not to be taken; because the sensible note must rise diatonically to the key, and therefore must not be doubled.





The chord of the sixth on the second of the key is the first inversion of the imperfect common chord. This chord alternates very agreeably either with the chord of the key, or with its first derivative, Nos. 5, 6, 7. In the progression of this chord of the 6th to the harmony of the key, it receives that peculiar treatment which is called the *resolution of a discord*. The dissonant interval is the lesser fifth, or (as it appears in these examples from the position of the chord) the greater fourth from F to B. The B rises to C, and the F falls to E: hence it is, that in Ex. 5 and 6, the second and third parts meet in unison; because to avoid consecutive octaves between the bass and third part, this latter also rises to E.

The 6th in this chord is the sensible note, and the harmony of the key follows it as a matter of course. This is therefore really a *dominant* chord as decidedly as the common chord of the fifth of the key. We shall afterwards find these two chords, viz. the common chord of the fifth of the key, and the imperfect common chord of the major seventh, or sensible note, united, form what is called the dominant seventh. In examples 8 and 9, the progressions of this chord of the sixth are exhibited in the minor mode, where the student will observe that the sixth is *accidentally* sharpened that it may be major, which is intimated in the figuring by the dash through the figure, thus 6̸; and thus the chord of the sixth on the second of the minor scale becomes similar to that of the major scale, and receives exactly the same treatment. This major sixth, being the sensible note, ought never to be doubled. But when this chord of the sixth is treated without regard to its dissonant nature, as in some of the following examples, the sixth may be doubled.

When the fourth of the key in the bass rises to the fifth of the key as leading chord, it is more agreeable and more usual to give the former a chord of the sixth, than a common chord; Ex. 10. This chord of the sixth, on the fourth of the key, is the first inversion of the common chord of the second of the scale; yet the harmony in this progression is felt as belonging to the subdominant. We shall afterwards see that the subdominant may have its proper fifth along with this sixth, and that the whole subdominant chord thus formed, is made up of the common chords of the fourth and of the second of the scale united. In the minor mode this chord of the sixth on the subdominant, is the same inversion of the imperfect common chord, which, in the major mode belonging to the seventh of the scale, governs the tonic harmony. Here it belongs to the second or to the fourth of the scale, and receives a different treatment accordingly; Ex. 11. We shall afterwards find that this combination may belong to the dominant of the major, or to the subdominant of its relative minor; or, lastly, to the dominant of the same relative minor. We shall, however, find, when we come to speak of a system of perfect and untempered harmony, that all the intervals do not exactly coincide in all these cases.

The chord of the sixth on the seventh of the major scale, may descend diatonically on the common chord of the relative minor, and then it forms an inversion of the interrupted cadence; Ex. 12. which is the beginning of a beautiful duet of Mozart, only transposed into the key of C; in which the other examples are written.

When a common chord descends a third to a chord of the sixth, the fundamental progression is the descent of a fifth to another common chord; and when a chord of a sixth rises one degree to a common chord, the fundamental progression is the ascent of fourth from one common chord to another. Ex. 13. is therefore the same fundamental progression as Nos. 1, 2, 3. in art. 110; which is pointed out by the dots under each chord of the sixth. Ex. 14. is the same fundamental progression as Nos. 6, and 7. in art. 110; as shown by the dots under each chord. Ex. 15. is the same fundamental progression, consisting entirely of chords of the sixth.

The common chord is succeeded by a chord of the sixth, on the same bass, in a very agreeable manner; and when the bass of this second chord rises diatonically to a new common chord, which is again succeeded by a chord of the sixth on the same bass, the progression forms what is called a *sequence* of fifths and sixths. Ex. 16. is written in four parts; by leaving out the third part next the bass, which consists of the octave and doubled sixth alternately, we have the sequence in three parts, in which form it more frequently appears. This is a very beautiful and effective progression, much in use by the first masters.

Chords of the sixth are used with far greater freedom than the common chords from which they are derived. A series of common chords ascending or descending diatonically in similar motion of the parts, would be quite intolerable. Yet this is a treatment which chords of the sixth frequently receive from the best composers. Nos. 17 and 18 are examples of such *sequences* of sixes ascending and descending. The reader will observe, that between the first and second parts there is a continual succession of perfect fourths; but the bass part at the distance of a third from the lower, so *covers* the fourths, that the succession gives no offence. Yet the same succession of fourths without the bass, or *naked*, would be as offensive as so many perfect fifths. If the bass be removed an octave lower, at a distance of tenth from the other part, the effect of the series of fourths becomes more observable, insomuch that Mr. Kollmann absolutely prohibits it. However, we shall find examples of a series of sixes, where the bass is at the distance of tenth from the second part, in good authors. The removal of the second part an octave higher, to alter the position of the chords, would produce a series of perfect fifths. The form here given is therefore the only one in which this sequence can take place. In these two examples, the sixth on the second of the major scale, in which the fourth is major, is treated as a discord: but this is done merely for the sake of a kind of termination; for this sixth is in such sequences used as freely as the others, its dissonant nature being, from the regularity of the succession, overlooked.

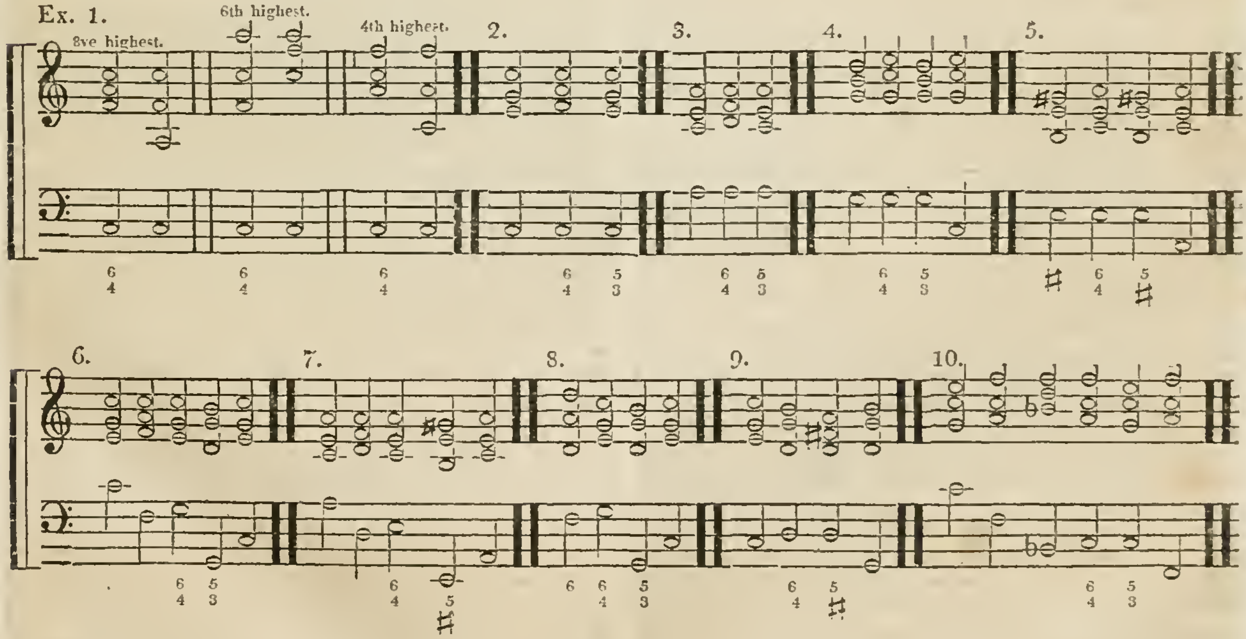
The bass may be doubled in the octave below; or four *real* parts may be had by putting the bass an octave lower, and taking to it an 8th and doubled 6th alternately, as in No. 19. This example is taken from Shield's Introduction to Harmony; and we shall quote the observations with which this excellent author accompanies it. "The bitter cries of naked fourths are so shocking to the ears of a feeling composer, that he never suffers them to remain long in any situation without clothing: How disagreeably this group (of fourths in the two upper parts) howl without their associate! But how pleasantly they sing in four parts, when he and his companion the eighth join them!" that is, the sixth and eighth reckoned downwards from the highest note. In this example, the reader will observe that the dissonant sixth, on the fourth of the minor scale, is here avoided by flattening the E: but he will find the effect still very good, by playing E natural instead of it. The student may also observe the manner in which the accidental flat and sharp are signified in the figures of the bass; by the ♭ 6, and by the $\not{6}$: the dash through the last signifying that the sixth is to be taken semitone higher than the minor scale of D would give it.

No. 20. is a series of alternate common chords and sixes, which is the progression in No. 12. carried through the descending scale.

We shall conclude the subject of sixes for the present, by another example from Mr. Shield, No. 21. which he says "is a stream of harmony produced by a link of sixes, which has often delighted the attentive ear." The passage is for two violins, tenor and bass: but the player on keyed instruments, by taking the whole chord of sixth in the left hand, and playing the highest part with the right, may hear the whole harmony, except when the highest and second parts become unisons.

117. The second inversion of the common chord, the $^{6}_{4}$, like its primary, has three principal positions, as exhibited example 1st. This chord is far more constrained in its use than either the common chord or the chord of the sixth. As an inversion of the common chord, it is usually considered by writers on the subject of music as concordant. Yet the treatment it usually receives makes it almost class with discords. The interval of 4th cannot in itself be called dissonant. A discord, properly so called, is felt to be such, however its position may be changed, or however it may be inverted. Thus the imperfect common chord is dissonant in all its inversions. The imperfect fifth or greater fourth will retain their dissonant nature in every combination, and in every position. But the interval of perfect 4th enters into the most perfect of all concords, as between the fifth and eighth of the common chord. Yet the interval of perfect 4th, reckoned from the bass, is unsatisfactory in itself, and points as strongly to a succeeding third on the same bass, as any discord does to its resolution; and in this the chord of $^{6}_{4}$ decidedly participates. We do not wonder, therefore, that some should have been disposed to rank it among the discords.*

On a stationary bass, the chord of the $^{6}_{4}$ is struck freely after the common chord, either major or minor: and this alternation frequently takes place on the key-note, or on the fifth of the key, Nos. 2, 3, 4, 5. When the $^{6}_{4}$ is succeeded by the common chord, it is usual to figure the latter by 3 or $^{5}_{3}$: and in the minor mode, the accidental sharp in the dominant chord is figured by ※, which signifies that the chord is to be taken a semitone higher than as given by the scale, as in No. 5. The reader will observe, that the sixth is major in the major mode, and minor in the minor, both on the key-note and on the dominant.



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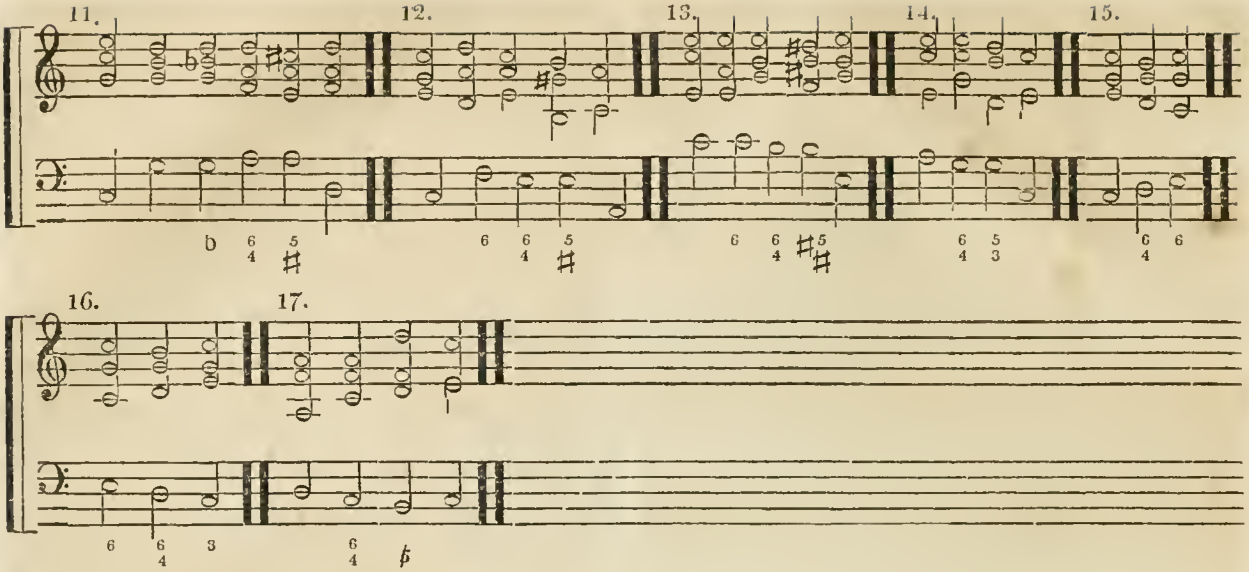
[*] Since this article was sent to press, we have had the satisfaction of receiving the Elements of Composition of ALBRECHTSBERGER, the friend of HAYDN, and the master of BEETHOVEN; and we are happy to quote so high an authority in corroboration of the view we have given of this chord. "Some authors," says he, "rank among the consonances the perfect fourth, accompanied by the major sixth and perfect octave, because it arises from the second inversion of the perfect chord; or, according to others, because in the perfect chord itself it occupies the highest part of the chord. Whatever name may be given it, I shall always reckon it a dissonance, and I shall have more than one reason with which to support my opinion."



The chord of the $^{6}_{4}$ is of great use in connecting chords, and smoothing the passage of one to another. Thus it entirely removes the harshness in the passage of the common chord of the subdominant to that of the dominant, Nos. 6 and 7. This progression is called the fourth and sixth cadence, and is one of the most formal and effective conclusions.

In general, when the bass moves, the 4th ought to be *prepared*, that is, heard in the chord, which is succeeded by the $^{6}_{4}$. We do not recollect to have seen this precept so formally laid down in any treatise; but we are sure it is sanctioned by the practice of the best masters. There is, however, one case in which it is not unusual for the $^{6}_{4}$ to be struck freely on a moving bass, namely, when the subdominant of the principal key, or even of a key well established, bearing a chord of the 6th, rises to the leading chord, No. 8.

As this chord points so strongly to a succeeding common chord on the same bass, it brings on very naturally a transition from the principal key to the related ones: and, though we must reserve an account of these transitions for another place, we shall here illustrate this use of the $^{6}_{4}$ by a few examples of them.

The chord of the principal key is the subdominant of the fifth of the key, considered as a new tonic; and by a progression similar to No. 6, a transition is easily effected to that new key, No. 9. After the same manner we may pass from the key to its 4th, No. 10. A similar progression, No. 11. leads to the second of the key, minor mode. The ♭ under the second G in the bass, signifies that the third is to be taken a semitone lower than in the original scale.

If the bass of a chord with major third descend a semitone, the 4th is prepared; and thus from the subdominant of the major mode, with third and fifth, or third and sixth, we may easily go to the dominant chord of the relative minor, No. 12. A similar progression, No. 13, carries to the third of the key, minor mode. If the bass of a chord, with minor third, descend a tone, the fourth is prepared; and thus we may go from the minor chord to the dominant of the relative major, No. 14. In all these cases the chord of the $^{6}_{4}$ is felt, and regarded as belonging to the bass note, on whose common chord it resolves, rather than to that of whose common chord it is an inversion, *i. e.* to the dominant which it *retards*, rather than to the harmony of the key, to which it leads.

These examples will suffice for this use of the $^{6}_{4}$. We may observe, in passing, that in writing all such passages in four parts, in which the bass ascends or descends by a single degree of the diatonic scale, the student must be on his guard against consecutive octaves, into which he might otherwise be easily betrayed.

The resolution of the $^{6}_{4}$ into the $^{5}_{3}$, of which we have given so many examples above, is the chief use that is made of it. It is, however, sometimes otherwise treated, in a gradual ascent or descent from the chord of the key to its first inversion, or *vice versa*, Nos. 15. and 16: or in a gradual descent from the second of the key to the seventh, bearing the chord of the imperfect fifth, No. 17; and in other similar ways which cannot be understood without a knowledge of chords which we have not as yet explained.

The chords of the fourth and sixth, above exemplified, are the inversions of the major and minor perfect common chords. The second derivative of the imperfect common chord is a discord, as is the primary chord itself. To this subject of discords we must now proceed more particularly to direct the attention of the student.

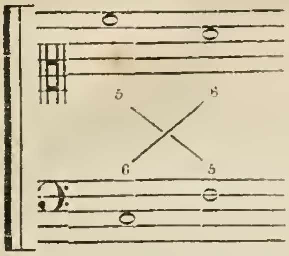
CHAP. III.

OF DISCORDS BY ADDITION TO THE COMMON CHORD.

Of the Dominant chord of Seventh, and its resolution in the perfect cadence, with the derived progressions.

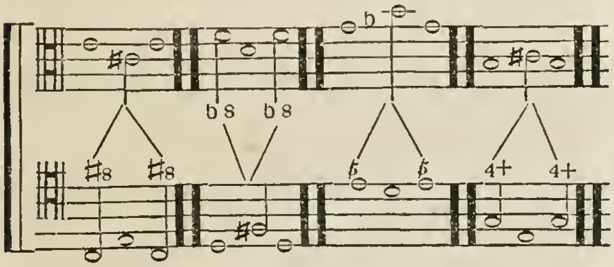
118. We shall begin this chapter with a short exposition of a rule for the movement of concords, which we have not hitherto noticed, but which it will be necessary to observe in some of the following examples. The rule is, that the two parts should be *concordant taken crossways.* This rule M. Choron gives under the head of *Relations*, and we shall be contented here with giving his explanation and examples, leaving a fuller exposition of the subject till a future opportunity.

"By the term Relation, which has not been as yet detined, is understood the interval which exists between the note taken by one part, and the note quitted by the other. Thus in the example here annexed, the first note of the



lower part is in relation of sixth with the second note of the uppermost, and the first note of this last part is in relation of fifth with the second note of the lower part.

"One conceives from this, that there are as many relations as intervals; but all relations are not equally admissible; those of the superfluous octave (*i. e.* increased by a chromatic semitone,) and of the diminished octave (by chromatic



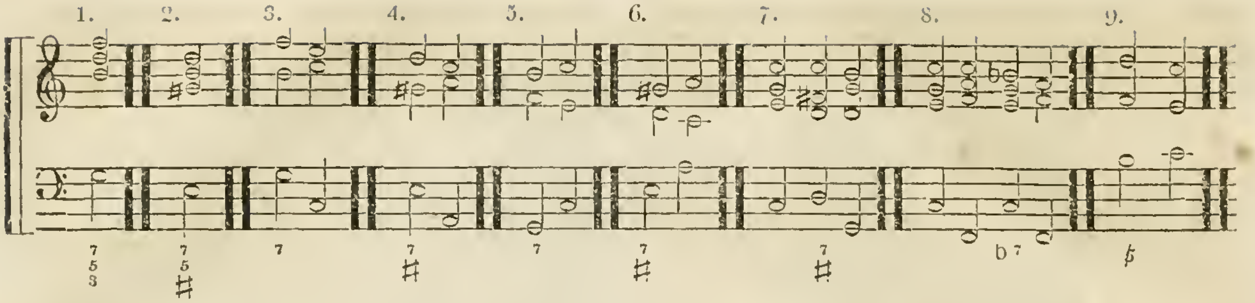
semitone,) of the lesser fifth and greater fourth are prohibited; in a word, the relations of octave, of fifth, and of fourth do not admit of any alteration, because, being altered, they make all the intervals appear out of tune; it is for this reason that they are called false relations, or bad relations. To be convinced of their bad effect, it is sufficient to repeat several times the above examples."

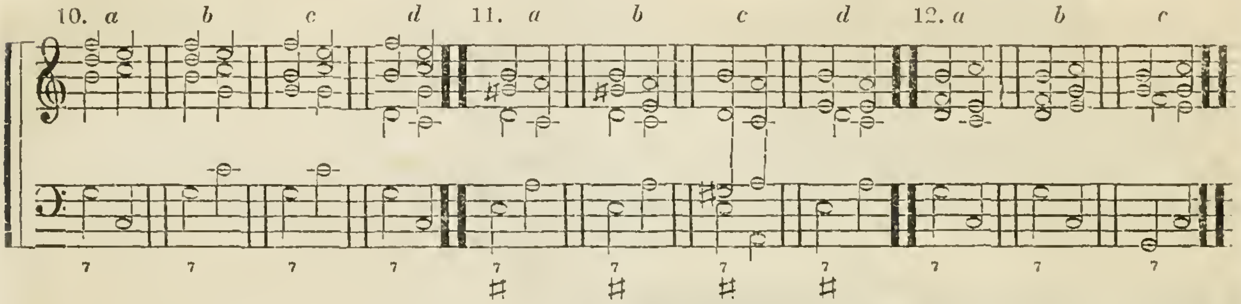
Whenever two major thirds follow in diatonic succession, there is the *false relation* of greater fourth taking the parts crosswise, and when two minor sixths follow diatonically, there is the cross false relation of lesser fifth. Yet both these are allowed in natural modulations within the key, of which examples will be found in every page almost of the best masters; as in the diatonic sequence of sixes, in which the former takes place between the fourth and fifth of the key, and the latter between the sixth and seventh of the key, carrying chords of the sixth, in the major mode, (see Nos. 17, 18. Art. 116.) The cross relation of greater fourth, or lesser fifth, is also generally disregarded in going from the sub-dominant to the dominant harmony of the principal key or related secondary keys. But when the false relations of octave crossways take place by accidental sharps or flats in transitions to other keys, they are offensive, and ought carefully to be avoided.

119. We are now to proceed to the subject of Discords; and we cannot introduce it better than by the following quotation from Dr. Burney's History of Music. "While harmony was refining and receiving new combinations, it was found, like other sweet and luscious things, to want qualification to keep off languor and satiety, when some bold musicians had the courage and address to render it piquant and interesting, by a mixture of discord, in order to stimulate attention; and thus, by giving the ear a momentary uneasiness, and keeping it in suspense, its delight became the more exquisite when the discordant difficulty was solved; and this contrast of imperfection seems a necessary zest to all our enjoyments. In painting, a tawdry glare of vivid colours without shade, would but dazzle and fatigue the sight. Discord, in musical composition, does not consist in the excess or defect of intervals, which, when false, produce jargon, not music; but in the warrantable and artful use of such combinations, as though too disagreeable for the ear to dwell upon, or for the purpose of finishing a musical period; yet so necessary are they to modern counterpoint, and modern ears, that harmony, without their relief, would satiate, and lose many of its most beautiful effects."

120. Discords are introduced into musical compositions in different ways, and they may be conveniently classed under the following heads: I. Discords by addition to the common chord. II. Discords by suspension and anticipation. III. Discords in passing notes on the unaccented part of the measure. IV. Discords produced by the chromatic alteration of intervals. The first of these classes is the subject of this and several following chapters. The others must be deferred till we shall have given an account of the doctrine of Time and Accent, without which they cannot be fully understood.

121. Of discords by addition, the most important are the dominant seventh and its derivatives. This chord is produced by adding to the harmony of the dominant, or common major chord of the fifth of the key, its minor seventh, which is the fourth of the scale; Nos. 1. and 2. In this combination, the most remarkable thing, and what most attracts the attention of the ear, is the lesser fifth between the third and seventh of the chord, that is, between the major seventh and perfect fourth of the scale. The resolution of this discord is by the movement of its two parts towards each other, each by one degree of the diatonic scale, so that they meet in a third major or minor according to the mode, Nos. 3. and 4. Or if the position of the chord invert this lesser fifth into a greater fourth, the resolution is by the movement of the two parts which form this interval from each other to a sixth minor or major according to the mode, Nos. 5. and 6.; and when the bass of the dominant, at the same time, falls a fifth, or rises a fourth to the key note, the whole progression is of the most satisfactory and conclusive nature. This is called the perfect cadence; but, as we observed, Art. 103. accent and rhythm contribute essentially to this conclusive effect, which we shall take an opportunity afterwards of illustrating with the fulness that its importance demands. Kirnberger and his followers call this the *essential* discord; but though we allow that the addition of the seventh to the dominant chord greatly heightens its effects, and makes it indicate still more expressly the succeeding tonic harmony, we cannot allow that the seventh is essential to the progression, or to its conclusive nature, and therefore we shall not adopt this phraseology. That our readers however may not misunderstand us, and suppose that we mean to say that this discord might be spared, we shall quote a sentence from Mr. Shield to show its importance. "The modern elegant Italian masters have produced, and do daily produce many charming compositions, without the assistance of any other discord than this minor seventh and its derivatives, when judiciously blended with concords."





This chord is figured $\begin{smallmatrix}7\\5\\3\end{smallmatrix}$, or simply with 7. But in the minor mode the major third to the bass is intimated by a ♯ placed below the other figure or figures as in Nos. 2, 4, 6. When by means of this chord the modulation is carried into another key, which requires an accidental sharp to make the leading chord major, this accidental is indicated by a ♯ under a 7, as in No. 7; and when the modulation goes to a key which requires an accidental flat to make the seventh minor, this is signified by the flat character before the figure, as in No. 8.

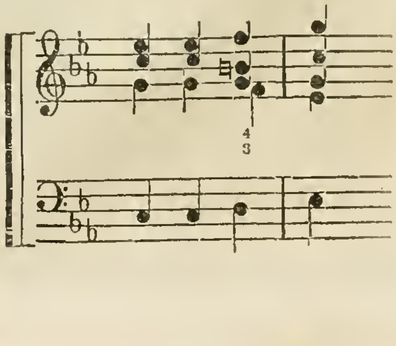
As, by the resolution, the third and seventh have a determined movement, they ought not to be doubled. In compositions of many parts the third may be doubled, being resolved only in that part where it is most conspicuous. We shall even sometimes find the seventh doubled and resolved only in one part.* The bass and fifth may be doubled in the octave or unison. In omitting parts of the chord, the octave to the bass, and the fifth, ought to be left out rather than the third, because this last characterizes the chord as the dominant. Cases however will occur when the third may fall to be omitted. If the seventh be left out, the chord is the common major chord of the fifth of the key; but as we have before said, it is still the dominant or leading chord in final cadences.

The dominant chord of seventh may be considered, as we have observed, Art. 116. as formed by the union of the major chord of the fifth of the key, and of the imperfect common chord of the major seventh of the scale. This last chord of itself most naturally points to the common chord of the key, No. 9; and all its inversions lead to the same harmony. See examples, Art. 116. Nos. 5, 6, 7, &c. As the two chords, therefore, point to the same succeeding harmony, and as their union forms a chord far from disagreeable, though requiring resolution, nothing can be more pleasing and satisfactory than this progression.

The chord of dominant seventh has different positions; and by the resolution the succeeding tonic harmony is placed in different positions. We shall therefore exhibit the chief of these with the resolutions, in four parts.

When the seventh is highest, the succeeding chord, by the resolution, has the third uppermost, No. 10, *a, b, c, d*. At *a*, the fifth of the leading chord may either rise, which doubles the third of the tonic, or it may fall on the octave, which is better; or in compositions for several voices or instruments, the fifth of the leading chord may fall on the fifth of the tonic, crossing the part in which the sensible note rises to the resolution on the octave; but then the bass and fifth must go in contrary motion, as at *b*; and this manner of taking the harmony may be allowed on keyed instruments. At *c*, the octave to the bass is taken, and the fifth omitted; and in this form the progression *phrases* better then the others, as each part is kept in its own place, and the harmony of the tonic is full. At *d*, the fifth is placed an octave lower than in the preceding examples. It may fall on the octave, or go to the fifth by contrary motion to the bass. Mr. Kollmann, indeed, positively allows two fifths in similar motion in the progression of the dominant to the key, and *vice versa*.

If the fifth of the leading chord be highest, it naturally resolves on the octave position of the tonic, No. 11, *a, b, c, d*. At *a*, the leading note and fifth meet in unison on the key; or these parts may cross as at *b*, which, however, is not very good here, as the highest part ought to keep its place. At



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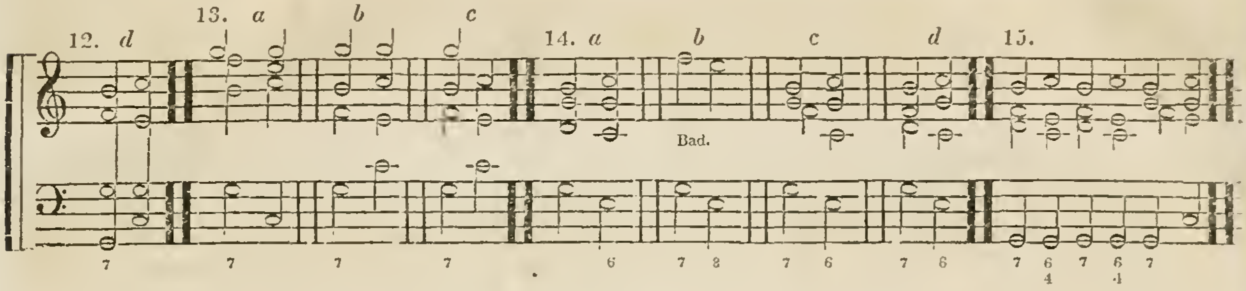
* A very remarkable instance of this doubling of the discord in the second derivative of the dominant, occurs in one of Mozart's quintetts; which example is here annexed. The movement is in the minor mode of C: at the end of the bar, F the discord is doubled; it is resolved in the part next the bass; in the highest part it rises to the fifth of the key, or third to the bass, and the imperfect fifth of the dominant is followed in similar motion by a perfect fifth in the two highest parts.

c, the sensible note is placed an octave lower, which makes the harmony more dispersed. At *d*, the octave to the bass is taken, and the sensible note omitted, which makes the conclusion less marked, and therefore less proper for the final close of a strain.

When the third of the dominant is highest, it necessarily resolves on the octave position of the tonic, No. 12, *a*, *b*, *c*, *d*. The two last, in which the octave is taken instead of the fifth of the leading chord, phrase better than the others, and give the tonic harmony full.

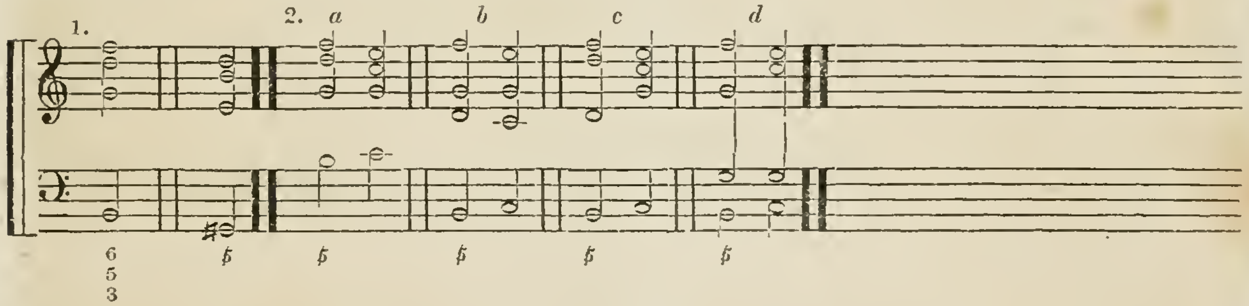


When the octave to the bass is highest, it naturally makes the tonic harmony in the position of fifth, which is the least conclusive, and therefore seldom found as a final close, 13, *a*, *b*. The extreme parts in full harmony may, however, meet on the octave by contrary motion, as at *c*.

The dominant chord, without the seventh, leads very well to the first derivative of the chord of the key, as No. 14, *a;* but when the seventh is added, this progression cannot very well take place, because the resolution of the seventh on the octave to the note taken by the bass, has an effect similar to consecutive octaves, *b*. This progression, however, is sometimes practised in full harmony, which is a license; but in that case the resolution being taken by the bass, the seventh descends a fourth to double the sixth as at *c*, or ascends to the third as at *d*.

The dominant seventh is frequently resolved on the $^{6}_{4}$ on the same bass, that is, the second derivative of the tonic chord; and the two chords are not unfrequently made to alternate on a continued bass several times, as in No. 15. It is scarcely necessary to observe, that this resolution is never the final close; the final resolution into the fundamental harmony of the key generally succeeds as in this example; or some other cadence, as we shall see afterwards.

122. As the dominant seventh consists of four real parts, it has three inversions: and we shall treat these with their resolutions, both in the major and minor modes, after the manner we have followed with the fundamental chord.

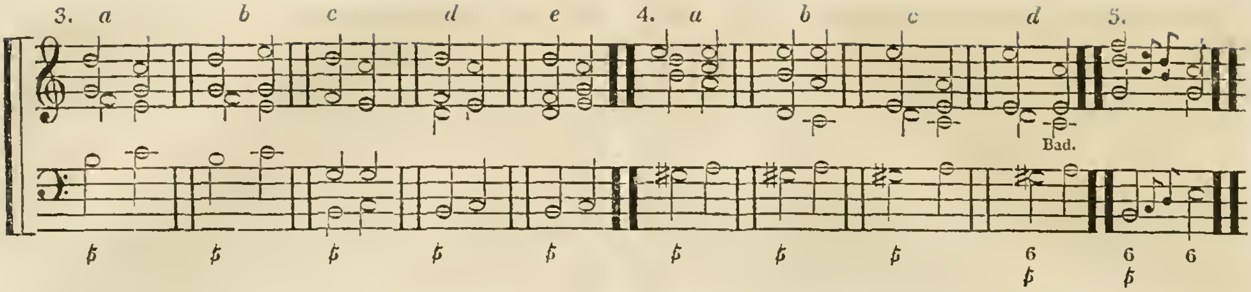


The first derivative, when the third of the fundamental chord is put in the bass, consists of a minor third, an imperfect fifth, and minor sixth; No. 1. This is called the chord of the false fifth, or the chord of the imperfect fifth and sixth. It is figured $^{6}_{5}$, to which the minor third is understood, and in a more abridged manner by a ♯ with a stroke through it, both third and sixth being understood.

The bass being the sensible note, must rise a semitone to the key-note, and the 5th being the discord, must descend diatonically on the third major or minor; and neither of these notes ought to be doubled, and they ought to be the last omitted. The third and sixth have no determined movement; and they may be doubled or omitted as most convenient.

All the positions of this discord phrase well, and it is easy to have all the parts of the succeeding tonic chord both in close and dispersed harmony. When the ♯, which is the discord, is highest, it resolves on the tierce position of the tonic, No. 2. At *a* and *b* we have all the parts in both chords; at *c* the 3d is doubled, and the 6th omitted; at *d* the 6th is doubled and the 3d omitted.

When the third is highest, it may either resolve on the octave position of the tonic, as No. 3. *a*, or on the tierce position, as at *b:* the former is better and more conclusive, but the other will often be induced by the melody. At c the same in dispersed harmony; at *d* the third is doubled, the one rising to the third, in order to avoid octaves; or the parts may cross as at *e*, and this resolution of the chord may even be allowed in accompaniments on keyed instruments.


3. a b c d e
4. a b c d
5.
Bad.
$\not{5}$ $\not{5}$ $\not{5}$ $\not{5}$ $\not{5}$ $\not{5}$ $\not{5}$ $\not{5}$
6 $\not{5}$
6 $\not{5}$
6

If the 6th be highest it will naturally keep its place, which puts the succeeding chord in the position of fifth, No. 4. *a*, *b*; or it may descend to the key-note as at c; but it would have a bad effect to make it descend to the third, as at *d*, because this would feel like octaves between the 6th and $\not{5}$th.

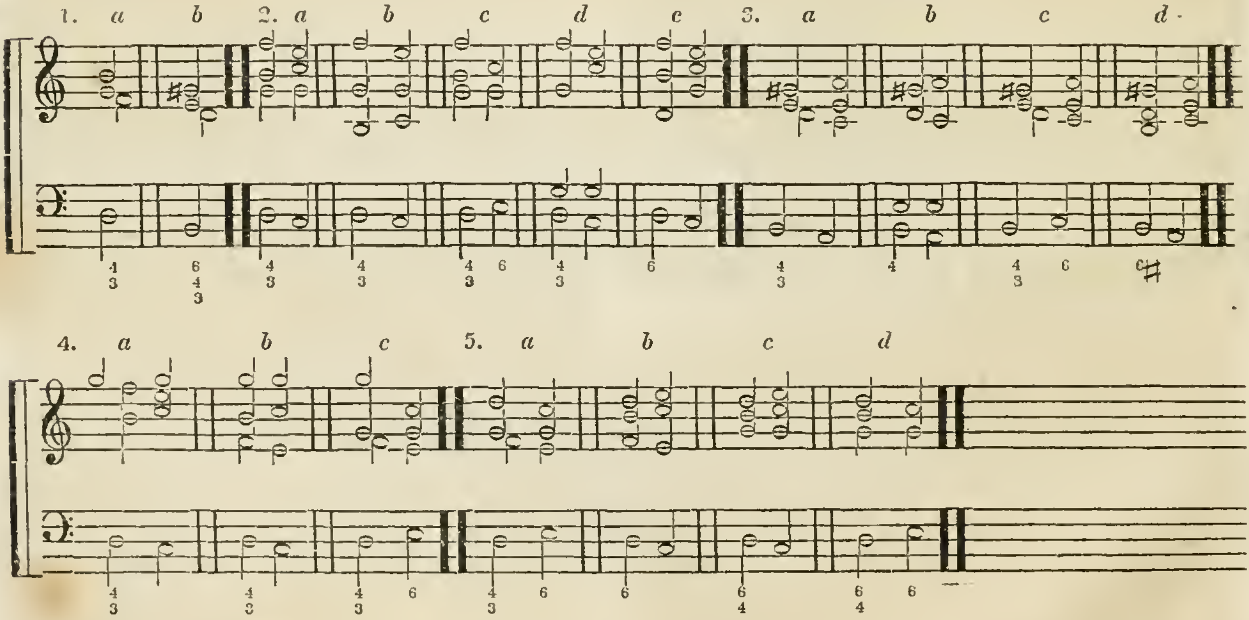
M. Choron gives the irregular resolution of the $\overset{6}{\not{5}}$, No. 5, which he says "is good, (by means of the notes of passage, which conduct the 4th [*i. e.* the 4th of the key, or discord] to the key-note,) in order to avoid the octave. This succession takes place, when the bass, or the highest part, has necessarily one of the motions, which we see in this example, as happens in a given subject."

If the $\not{5}$, which is the discord, be omitted, the chord is 6th on the sensible note, as shown Nos. 3 and 4. Art. 116.

The resolution of the $\overset{6}{\not{5}}$, taking place on the proper part of the measure and rhythm, forms an inverted cadence, which Dr. Callcott calls the cadence of the *leading note*.

123. The second derivative of the dominant seventh, in which the 5th of the fundamental chord becomes bass, consists of a minor third, perfect fourth, and major sixth. It is figured $\overset{4}{3}$, the major sixth being understood; No. 1, *a*, *b*. Dr. Callcott observes, that the older masters, as Handel, Corelli, &c. have uniformly omitted the 4th, (which is the fundamental sound,) and then the chord is the first inversion of the dissonant 5th, and is figured by 6, as in Art. 116, 5, 6, 7, 8, 9. When an accidental is required to make the 6th major, it is signified by a dash through the figure thus $\not{6}$, or by a sharp before it thus ※6.

In this inversion the 3d is the discord, and the 6th is the sensible note; therefore neither of these ought to be doubled, and they ought to be the last omitted. The third descends diatonically to the resolution, and the sixth rises semitone. The bass and 4th are not restrained to any particular motion.



When the 3d, which is the discord, is highest, it resolves on the fundamental tonic chord in the tierce position, as No. 2, *a*, *b*. If instead of this the bass rise to the third of the key with chord of 6th, M. Choron forbids the resolution of the discord on the octave, and directs that it should fall to the 6th, as at *c*, which is a license similar to that in Art. 121, No. 14, *c*: or he says the dissonance may ascend in thirds with the bass. Compare the example from Mozart, Art. 121, note. The prohibition, however, to resolve the discord on the octave, must be restricted to this case, in which these are the extreme parts; for otherwise it is very good, and will be found frequently exemplified in the best writers. At *d* the 4th is doubled, and the 6th, or sensible note, omitted, one 4th rising to the octave, and the other remaining as fifth in the second chord. At *e* the octave to the bass is taken, and the 4th omitted, when the chord becomes the 6th on the second of the key, but still treated as a dominant resolving on the key.

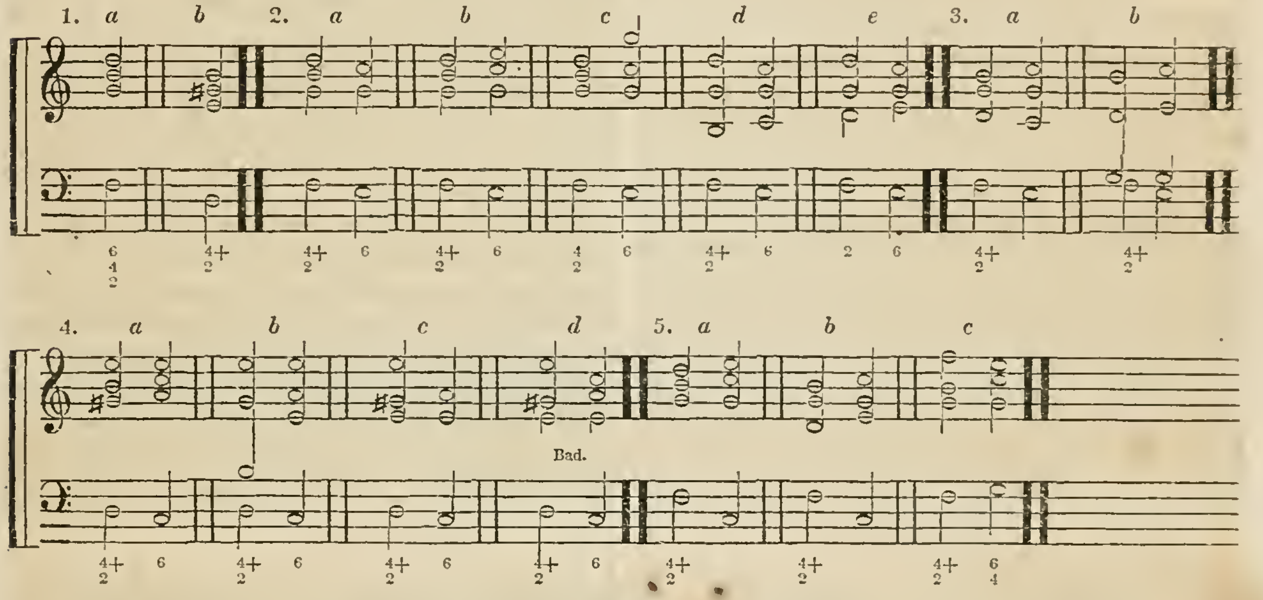
When the 6th is highest, the resolution is into the octave position of the common chord, No. 3, *a*, *b*, or into the chord of the 6th, as at c. In the example at *d* the 4th is omitted, and the octave to the bass taken, when we have the chord of major 6th on the second of the key; the middle parts may unite on the third, or may cross; and this way of taking the chord may be allowed on keyed instruments.

When the 4th is highest, it will keep its place, and the resolution will be into the common chord in position of 5th, as No. 4. *a*, *b*; or the bass may rise to the third of the key with chord of 6th; or the 4th being doubled, the highest may fall to the key-note, the bass rising to the third of the key with chord of 6th, as at *c*.

In No. 5, the octave to the bass is placed highest. At *a* the 6th is omitted, and the chord resolved on the chord of 6th. At *b* the 4th is omitted, and the 6th on the second of the key resolved on the common chord. At c and *d* the discord is omitted, when the chord appears as $^{6}_{4}$, yet treated like the dominant chord. Compare what is said, Art. 117, Nos. 15, 16.

124. The third inversion of the dominant seventh is that in which the discord is put in the bass. It consists of major second, greater fourth, and greater sixth. It is called the chord of the sharp fourth, or tritone: it is figured $^{4+}_{2}$ the sixth being understood.

The dash after the 4 signifies that it is major, not perfect. This dash is not necessary in the major mode of the original key, but is essential to indicate an accidental ※, as in the minor mode, or in any change of key by this chord; No. 1. *a*, *b*.



The bass being the discord, is not to be doubled, nor the 4+ which is the sensible note. These two intervals are resolved, as in all the preceding examples. The regular resolution is into the chord of sixth on the third of the key; but licences are sometimes used with this as with the fundamental and with the other inversions. When the 6th is highest, the resolution may be into the position in which the key note, or sixth to the bass, is highest, as No. 2. *a*, or the octave to the bass, as at *b*; this, however, M. Choron forbids; or the 6th may leap a 4th as at c. At *d*, the resolution is the same as at *a*, only in more dispersed harmony. At *e* the 4th is omitted, and the 6th doubled.

When the greater fourth is highest, it necessarily puts the succeeding harmony in the position at No. 3. *a*, *b*.

When the second is uppermost, it will keep the same degree, as No. 4. *a*, *b*; or it may descend on the key-note, as at *c*; but it ought not to descend on the octave to the bass, as at *d*, for the reasons formerly given.

At No. 5. *a*, *b*, the bass by license descends to the key-note, while another part takes the note on which the bass ought regularly to resolve. At c is a license much more unusual, which M. Choron says, although altogether irregular, is employed by the necessity of answering to some subject in fugues. If the dissonance ascend in the bass, it ought to be properly resolved in another part.

There are other forms in which the dominant chord appears both in the major and minor modes, the exhibition of which we shall at present delay. In the mean time we shall proceed, in the next chapter, to the consideration of other chords of the seventh.

CHAP. IV.

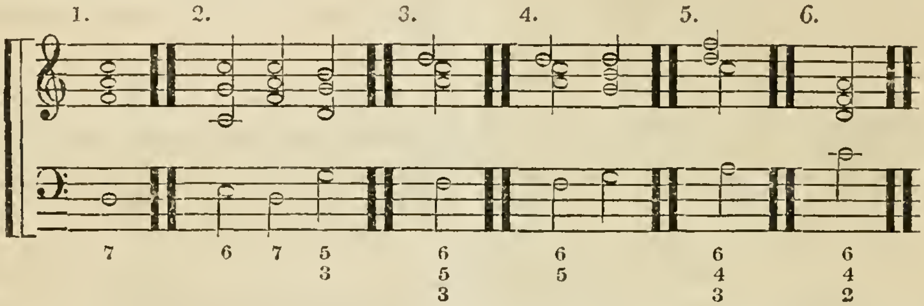
OF OTHER CHORDS OF THE SEVENTH: THEIR PREPARATION AND RESOLUTION ANALOGOUS TO THE PERFECT CADENCE.

125. If to the minor common chord of the second of the scale major mode, we add the key-note, we have a chord consisting of minor third, perfect fifth, and minor seventh, No. 1; of which chord Mr. Shield observes, that it is a chord less agreeable to the ear than the dominant chord, more restricted in practice, but not less essential to a regular stream of harmony.

The seventh in this chord must be prepared in the preceding chord. It resolves after the same manner as the dominant chord, that is, by the diatonic descent of the 7th on the major third of the dominant chord, and the ascent of the bass by fourth, or descent by fifth; but the interval between the third and seventh being perfect fifth, that third is not necessarily constrained to rise to the octave like the leading note in the dominant seventh; No. 2. From its resolution on the dominant, it may very well be called the *subdominant* chord of seventh.

This name of subdominant chord, however, is chiefly given to its first derivative, when the third of the chord, that is, the fourth of the key, is made bass; No. 3. This chord consists of major third, perfect fifth, and major sixth; or of a major sixth added to the common chord of the fourth of the key. But the 5th of the chord is the discord, which must be prepared, and resolved by descending semitone on the major third of the dominant chord; No. 4. This chord is called by some the great sixth, and it is figured $\substack{6\\5}$.

These two forms of the chord, viz. the 7th on the second of the key, and the $\substack{6\\5}$ on the fourth, are those chiefly in use, the latter even more frequently than the former; and both the progressions to the dominant are used as cadences to terminate phrases. It has been much disputed, whether the second or the fourth of the key is to be reckoned the fundamental. The question is of very little importance, as the manner of employing the chords is no way influenced by it. The whole combination, as we formerly observed, is made up by the union of the common chords of the second and of the fourth of the key.



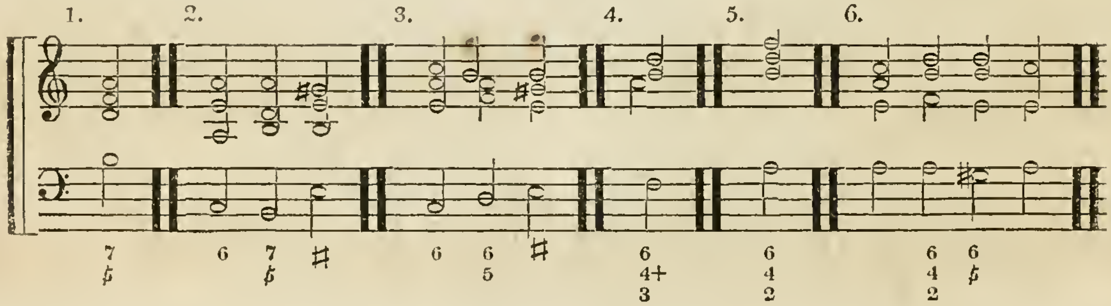
The 2d derivative, when the fifth of the chord of 7th is put in the bass, consists of minor third, perfect fourth, and minor sixth; No. 5. This inversion is much less frequently used than the preceding.

The third derivative, when the discord is in the bass, is more frequently met with than the last, though much less frequently than the $\substack{6\\5}$. It consists of major second, perfect 4th, and major sixth, and is figured by $\substack{4\\2}$, No. 6.

126. After the same manner, in the minor mode a seventh, which is the key-note, is added to the imperfect common chord on the second of the key, No. 1; and it consists of minor third, false fifth, and minor seventh. It is figured $\substack{7\\ \not{5}}$ the dash through the 5 intimating that it is imperfect.

This seventh is generally prepared, and it resolves in a similar manner on the dominant chord, No. 2.

Its first derivative, which consists of minor third, perfect fifth, and major sixth, figured $\substack{6\\5}$, in like manner resolves on the dominant, No. 3.



In all these cases, both in the major and minor modes, the dominant on which the subdominant chord thus resolves, may have its added seventh, though omitted in these examples.

Its second derivative, when the 5th is made bass, consists of major third, major fourth, and major sixth, No. 4. Its third derivative consists of major second, perfect fourth, and minor sixth, No. 5.

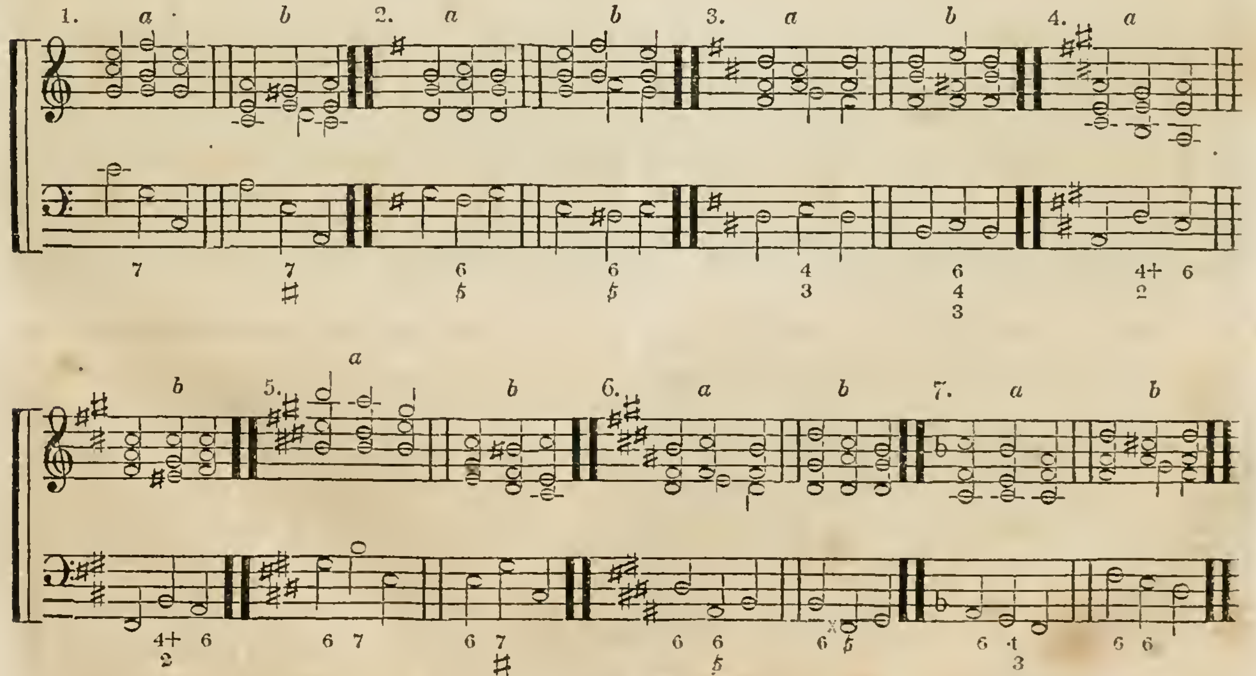
This chord and its derivatives, we shall afterwards find, are often treated as belonging to the dominant chord of the relative major mode. The chord of the seventh and the first derivative are treated both ways, *i. e.* are resolved either into the dominant of the minor mode, or into the tonic of the relative major; the second derivative is used chiefly in this last way; and the 3d derivative chiefly as the subdominant of the minor, resolving on the first inversion of the dominant, No. 6.

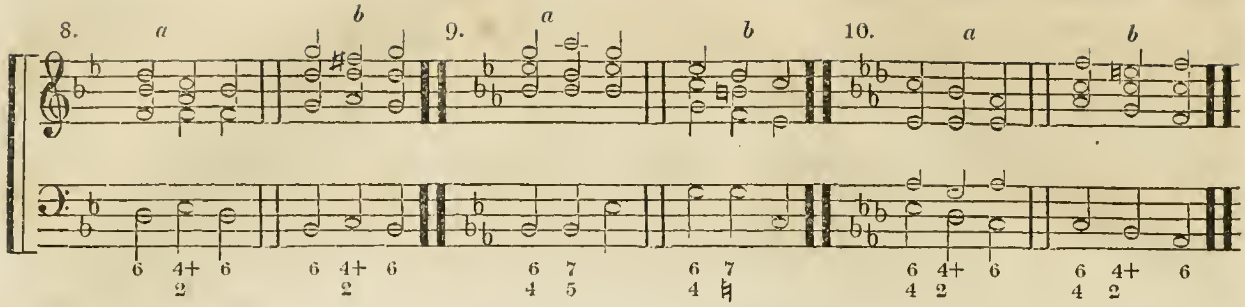
Though these two last described chords of the seventh, which we may call subdominant sevenths, with their derivatives, are figured in the same way as are the dominant seventh and its derivatives, yet the performer of thorough bass soon learns to distinguish what precise combinations are meant. There are other chords of the 7th, but these of the dominant and subdominant are the most important; and we shall now proceed to consider the manner in which these and the tonic harmony are interwoven in musical phrases, which indeed constitute, we may say, the substance of all modulations.

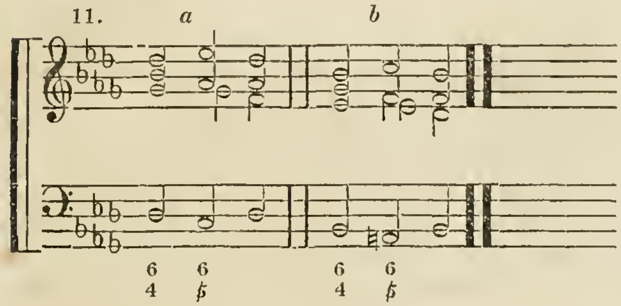
In our examples, hitherto, we have confined ourselves to the keys of C major and A minor, leaving it to the industry of the student to write and perform them in different keys; but as the diligent reader must now be familiar with the tonic and dominant harmonies, and their inversions in different positions, we think we may, without the risk of confusing him, write our subsequent examples in different keys. This will both relieve monotony, and assist the student in the exercise of transposition, which, indeed, is a simple business enough, though otherwise accounted of by many. We shall, at least for some time, observe a progressive order both in the major and minor modes.

127. The seventh of the dominant may be struck freely without preparation, or it may be prepared. When we proceed directly from the chord of the key to the dominant, the 7th is of course unprepared. This progression, with the inversions of both chords, is given in the examples following: No. 1. *a*, both the chords fundamental in the key of C major; at *b*, the same in the relative minor A, in a different position. No. 2. *a*, the chord of the key followed by the first derivative of the dominant in G major; *b*, the same in the relative minor E. No. 3. *a*, the chord of the key followed by the second inversion of the dominant, in D major; *b*, the same in B, the relative minor. No. 4. *a*, the chord of the key followed by the third inversion of the dominant resolving on the chord of 6th, in the key of A major; *b*, the same in F♯, the relative minor; here we require E♯ as leading note, which on keyed instruments is struck with the finger-key of F♮.—N. B. This direct progression from the key to the $^{4+}_{2}$ is not so usual as some others which follow, and is considered by some as a license; it has a good effect, however, in the course of a strain. No. 5. *a*, the first inversion of the tonic harmony followed by the dominant 7th, in E major; *b*, the same in C♯, the relative minor; here we must have B♯ for the sensible note, played on keyed instruments by the finger-key of C♮. No. 6. *a*, the first inversion of the tonic harmony followed by the first invercion of the dominant 7th in the key of B major; *b*, the same in that of G♯, the relative minor; here we require F double sharp, signified by the St. Andrew's cross, and played by the finger-key of G♮. No. 7. *a*, the first derivative of the tonic harmony in the key of F major, followed by the second derivative of the dominant. The reader will observe, that in this example, and in No. 5. *a*, a perfect fifth between the highest and second parts is followed by an imperfect fifth between the same parts in similar motion; but as the imperfect fifth is regularly resolved, this is reckoned quite legitimate by the strictest harmonists. At *b*, the same progression in the minor mode of D. No. 8. *a*, the first inversion of the chord of the key, followed by the third derivative of the dominant seventh in the major mode of B♭. This is a much more usual progression than that in No. 4; *b*, the same in the relative minor G.

The second inversion of the tonic harmony, or $^6_4$ on the fifth of the key, is frequently succeeded by the $^7_5$ on the same bass, in formal closes on the key; No. 9. *a*, *b* in the major mode of E♭, and minor of C, its relative. The $^6_4$ does not easily allow any motion of the bass, except by gradual ascent or descent: therefore this second inversion of the chord of the key cannot well be succeeded by any other derivative of its own dominant except the third, which progression is given in the major of A♭, and in its relative minor F, No. 10. *a*, *b*. This inversion of the chord of the key might proceed to other derivatives of dominant chords effecting a change of key; or the $^6_4$ on the key-note, which is the second inversion of the common chord of the fourth of the scale, may be succeeded by the first derivative of the dominant, the bass descending semitone; which is exhibited in the major mode of D♭, and the minor of B♭, its relative, No. 11, *a*, *b*. With this example we close this article, and in the next proceed to exhibit examples of the subdominant with the tonic, the dominant, and other harmonies.







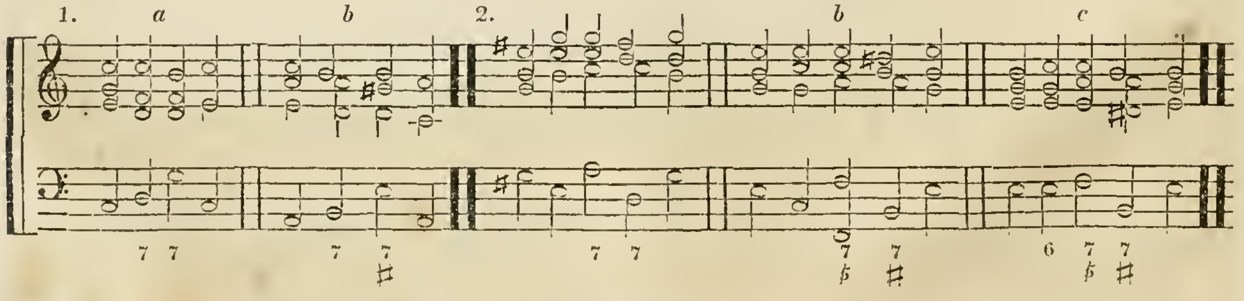
128. We have already shown the chord of seventh on the second of the key prepared in the first inversion of the tonic chord, Art. 125. 2. 126. 2. both in the major and minor mode. Here we exhibit the chord prepared in the fundamental tonic chord, No. 1, *a, b,* and resolved on the dominant chord of seventh. When one fundamental chord thus rises diatonically to another fundamental chord, one is very apt to be betrayed into consecutive fifths. This is avoided in these examples, by the motion of the parts in the opposite direction to that of the bass, and, consequently, the fifth of the second chord is omitted. As in the minor mode the fifth, in the chord of the second of the scale, is imperfect, the reader might suppose that here the 5th of the first chord might proceed to the imperfect fifth of the second. But when the imperfect fifth is treated like a consonant interval, that is to say, not resolved as in the dominant chord, such consecutive fifths ought to be avoided as if they were both perfect. The reader will observe, that the 7th in the dominant chord is here also prepared in the third of the *subdominant seventh.* When one chord of seventh thus succeeds another, the bass rising fourth or falling fifth, the progression is called a sequence of sevenths; and we shall afterwards find such sequences going through the whole scale, in which every note of the scale bears that chord of seventh, which arises by adding its seventh to its common chord.

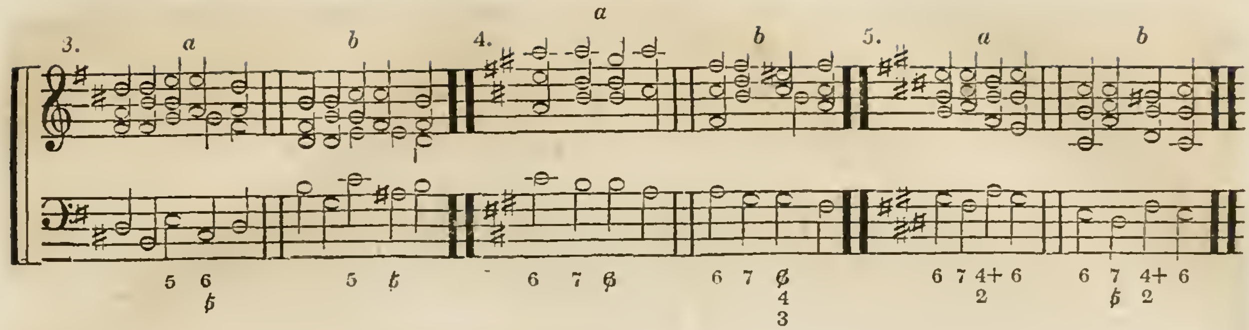
By interposing the chord of the relative minor between the tonic chord and our subdominant seventh, we may have the latter full in all its parts. The 7th is prepared in the 3d of the minor chord; No. 2. *a,* in the key of G major. After the same manner, in the minor mode, the chord of the 6th of the scale prepares the subdominant 7th on the second of the scale; and here the motion of the bass is greater 4th upwards, or imperfect 5th downwards, *b;* or the first inversion of this harmony, *i. e.* the chord of sixth on the key-note, may prepare the seventh on the second of the scale as at *c.*

Our subdominant 7th cannot proceed to the first inversion of the dominant, because the resolution of the 7th on the octave, would have a bad effect; and, besides, that being the sensible note, ought not to be doubled; but the common chord on the second of the scale, may take the first inversion of the dominant as in No. 3. *a, b,* in the key of D and its relative minor B.

The subdominant seventh very frequently resolves on the second inversion of the dominant; and in this case the 4th of the chord of $\begin{matrix}6\\4\\3\end{matrix}$ is generally (but not necessarily) omitted, and the dominant is a simple chord of the 6th, as No. 4, *a.* This is called a sequence of sevenths and sixths, and might be carried, as we shall afterwards see, through the whole descending scale. At *b,* the same progression is exhibited in F minor, the relative of the former; and here the second inversion of the dominant is taken in all its parts.

A less frequent resolution of the subdominant seventh, is into the third inversion of the dominant, which however is of good effect, No. 5, *a, b.* In such a progression, it is more usual to give the second of the key a *dominant* chord, *i. e.* major third and perfect fifth, with the minor seventh; and even then, the movement of the bass third upwards, or sixth downwards, to the discord of the succeeding dominant, instead of fourth upwards, or fifth downwards, to its fundamental, is to be reckoned a license; a happy one, indeed, and productive of a grateful variety.





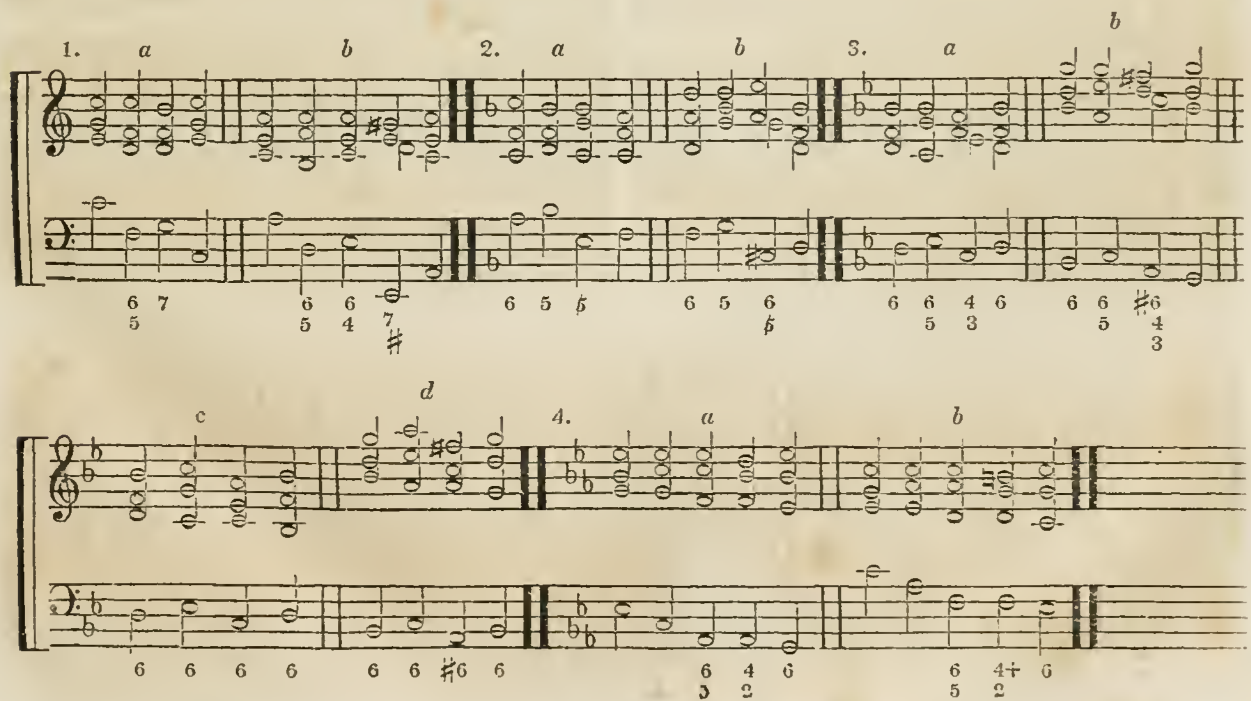
129. The first inversion of the subdominant seventh, the $^{6}_{5}$ on the fourth of the key, is a chord of more frequent use than even the fundamental chord of which we have been treating. It is most generally prepared in the common chord of the key, or that of the sixth of the key, or their first derivatives. It resolves directly into the dominant chord, or into its derivatives; its resolution into the fundamental dominant is frequently interrupted by the chord of $^{6}_{4}$ on the dominant bass.

No. 1, *a*, the $^{6}_{5}$ of the subdominant is prepared in the tonic, and is resolved directly into the dominant 7th. At *b*, the same progression in the minor mode, only that the chord of $^{6}_{4}$ on the dominant bass, interrupts the resolution of the 5th, which is the discord, and which is *suspended* as 4th to the bass, before its resolution on the major third. In consequence of this interruption, the 7th of the dominant is struck freely, whereas it is prepared when the $^{6}_{5}$ proceeds directly to its resolution. On the other hand, the imperfect fifth of the subdominant chord, (between the 6th and 3d,) is regularly resolved on a major third, in consequence of the interposing of the $^{6}_{4}$ before its resolution into the dominant.

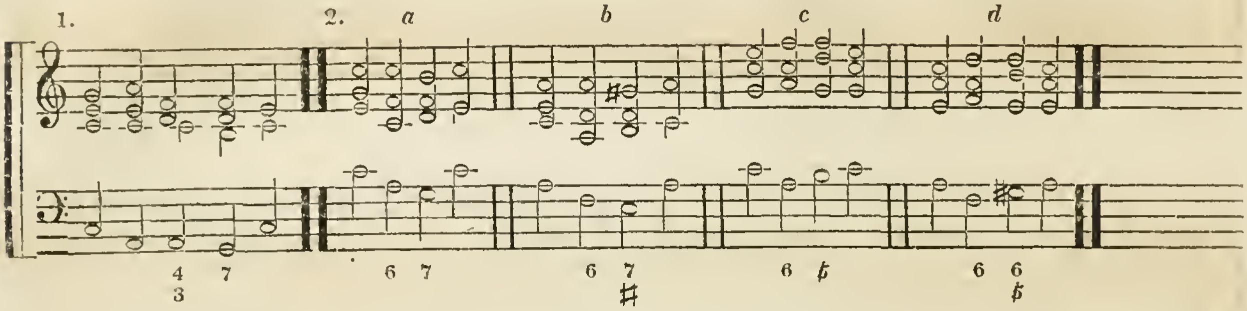
The subdominant $^{6}_{5}$ cannot properly proceed to the first inversion of the dominant, because of the resolution of the 5th, which is the discord, on the octave to the bass, which, besides, is the sensible note, and ought not to be doubled. But if we omit the 6th, (which is what makes the 5th a discord,) we have the common subdominant chord on the fourth of the key; and this common chord may proceed by leap of lesser 5th, downward, or major fourth upwards, to the first derivative of the dominant; No. 2, *a*, *b*.

Our subdominant $^{6}_{5}$ resolves well enough on the second inversion of the dominant, No. 3, *a*, *b*. By leaving out the 5th in the subdominant chord, (which is the discord,) and the 4th in the second derivative of the dominant, (which is the fundamental sound,) this progression may consist entirely of sixes, as at *c*, *d*.

A resolution of the $^{6}_{5}$, still more agreeable, and more practised, is into the third inversion of the dominant; the bass continuing in the same degree, until the resolution of the dominant $^{4+}_{2}$ on the chord of sixth, No. 4, *a*, *b*.



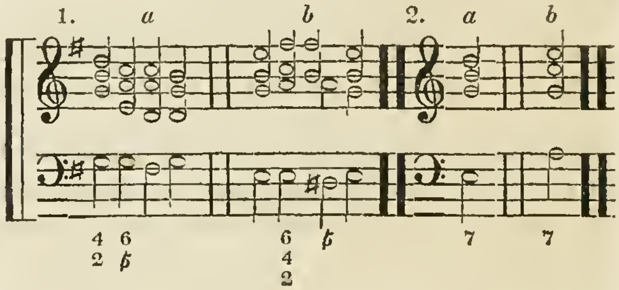
130. The second inversion of the subdominant seventh on the second of the scale is hardly in use. Following the analogy of the chords we have been treating of, it might be prepared and resolved as in No. 1. The effect, however, is not very attractive. By omitting the 4th, (which is the fundamental sound of the subdominant seventh,) the chord becomes the first inversion of the subdominant common chord on the fourth of the scale; and this chord of sixth proceeds very well to the dominant seventh, as in No. 2, *a*, *b*; or to its first derivative, as at *c*, *d*. To the last some would object, because of the motion in the bass, by redundant second from F to G𝄪.*



131. The third inversion of the subdominant seventh on the second of the scale, viz. the $\substack{6\\4\\2}$ on the key note is pretty frequently to be met with. The discord, which is the bass, is prepared in the common chord of the key, and it resolves on the dominant $\substack{6\\5}$, No. 1, *a*, *b*.

We have now got acquainted with three species of chords of the seventh—the dominant on the fifth of the scale, much the most important of all; in which the minor 7th is added to the major common chord—the chord of seventh on the second of the scale major mode, being the minor 7th added to the minor common chord, and the chord of seventh on the second of the scale, minor mode, being the minor 7th added to the imperfect common chord. These two last we have ventured to call subdominant sevenths; though of less importance than the dominant and its derivatives, they are of much value, and sometimes produce admirable effects. Of both, the first derivative is more frequently to be met with than the fundamental chord of 7th.

The dominant seventh is to be found only on one part of the diatonic scale, viz. the fifth, and the subdominant seventh of the minor mode is to be found only on one note, the second; but we may find chords of the seventh exactly resembling that on the second of the major mode, on two other notes of the scale, viz. the third and sixth of the major mode; or the key-note and fifth of the minor mode, No. 2, *a*, *b*. These chords are used chiefly in a sequence of sevenths.



132. There is yet another species of chord of the 7th to be found in the diatonic scale, viz. the major seventh added to the major common chord; which chord has its place on the key-note, and fourth of the major mode; or on the third and sixth of the minor; No. 1, *a*. *b*. The seventh in this chord is always prepared, and it is resolved by the diatonic descent of the 7th on the third of the succeeding chord; the bass falling fifth, or rising fourth.

This chord of major seventh has also its inversions. By putting the third in the bass, we have a chord consisting of minor third, perfect fifth, and minor sixth, No. 1, *c*. This chord is sometimes to be met with.

By putting the fifth on the bass, we have a chord consisting of major third, perfect fourth, and major sixth; a chord scarcely used, except perhaps as a passing chord on the unaccented part of the bar; No. 1, *d*.

By putting the seventh in the bass, we have a chord con-

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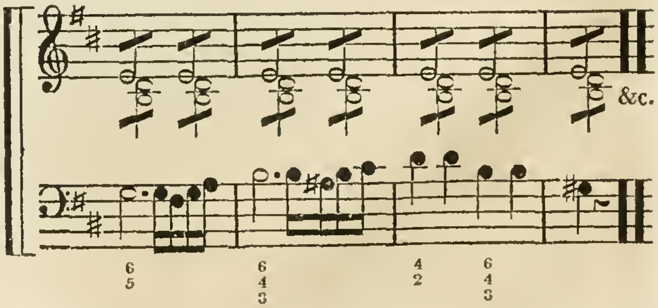
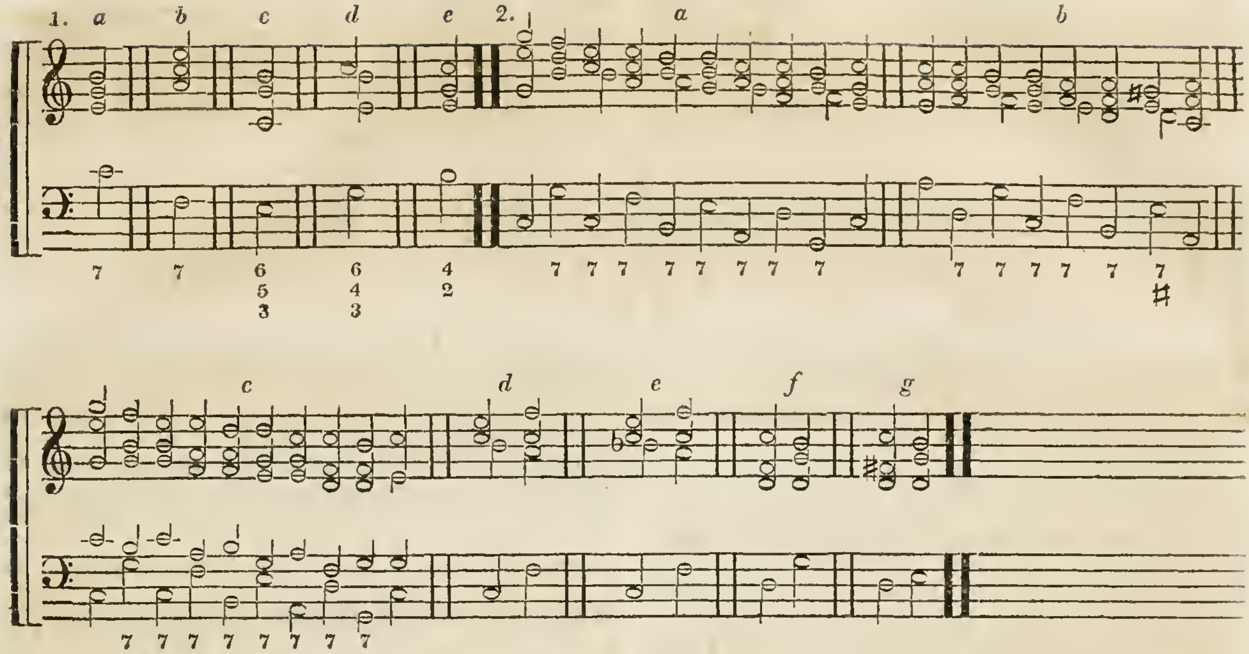
* Dr. Callcott has quoted an instance of the use of this second inversion of the subdominant seventh, from Handel's Overture to Esther. Here is another from a symphony of Beethoven, in which all the three inversions are taken one after another.



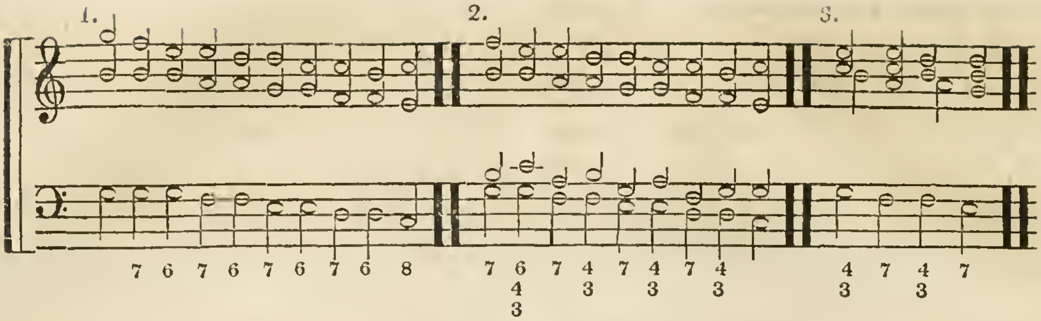


sisting of minor second, perfect fourth, and minor sixth. This last chord is of better effect, and much more frequently used than the others. No. 1, *e.*

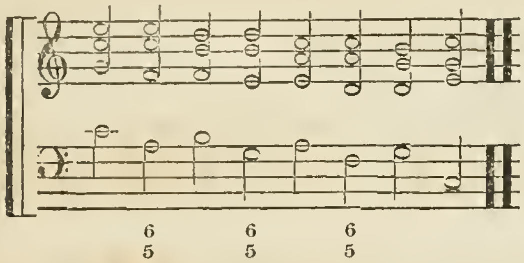
These chords of the major seventh make part of the diatonic sequence of sevenths; which we shall now exhibit both in the major and minor scales, with a few remarks.

No. 2, *a,* is a sequence of sevenths, in which every note in the major scale bears the chord of seventh belonging to it. The dominant seventh is struck freely, but all the others are prepared in the third of the preceding chord; and for this purpose the third of the dominant remains in its place, instead of rising semitone to the resolution, as in a final close. At *b,* a similar sequence in the minor mode. At *c,* is the same progression in five parts; and here is an instance in which the sensible note, or third of the dominant, may be legitimately doubled; it is resolved regularly in one part, and in the other prepares the major seventh of the succeeding chord. The octave proceeding to the third of the next chord, while the seventh resolves on the same third, is allowable in harmony so full. By the position of the chord of major seventh to C, in the example *a,* the octave struck along with the seventh, makes an interval of semitone, which is rather a harsh combination, though musicians make no scruple of frequently introducing it in their compositions. The position of the same chord to F, is much less harsh. In the example *c,* both the chords of major seventh are in such a position, that the interval of minor second is avoided. The student will observe that the first chord of major seventh proceeds to a second of the same kind; and this latter, by movement of the bass, lesser 5th, proceeds to the imperfect chord of seventh on the sensible note. The progression of this imperfect chord to the minor seventh with minor third, is not so agreeable, as, in the minor mode, the progression of the same imperfect chord (on the second of the scale) to the dominant chord, as at *b.* We have three minor chords of the minor seventh in succession, the last resolving on the dominant of the major scale. Lastly, the reader may observe how much superior and how much more conclusive is the resolution of the dominant chord than that of any other of these sevenths. To convince himself of this, the reader has only to resolve the third of any one of them upwards in the octave to the bass, as if to make a conclusion, (instead of continuing the third as seventh to the succeeding chord,) and he will feel how comparatively unsatisfactory such conclusion is. If he make the trial with the chord of major seventh, let him then substitute a minor seventh, and compare the effect, as at *d, e;* or if he make the trial with the minor chord of seventh, let him then substitute a major third, as at *f, g.*

133. This diatonic sequence of sevenths is frequently met with both in ancient and modern authors; of which a good many examples are quoted by Mr. Shield, in his *Introduction to Harmony,* p. 79. The descending sequence of sevenths and sixths, which is also a very frequent passage, is derived from it; which the reader will easily see by comparing the example of it in No. 1, in this article, with the example No. 2, *c,* in the last: for the sequence of 7 and 6 is no other than the notes in the upper line of that example; the lowest notes being removed an octave lower. It appears, therefore, that the chord of the sixth, which follows on the same bass, is the $\begin{smallmatrix}6\\4\\3\end{smallmatrix}$, second inversion of the chord of seventh to the fifth below. But as this inversion of the 7th is not agreeable, except that of the dominant seventh, the 4th is omitted, and the chord appears as a 6th. Compare what is said of the examples, Art. 128, 4, *a, b.* Hence this sequence is usually written in three parts. By writing the part next the bass in Art. 132, *c,* over the bass of this sequence, we have four parts, and the $\begin{smallmatrix}6\\4\\3\end{smallmatrix}$ complete in every second chord, No. 2. But the reader will hardly think this an improvement: No. 1. is pleasing and attractive; No. 2. barely tolerable. Mr. Kollmann, in his thorough bass, gives this progression as in No. 3; the effect of which is not very bad: though certainly very inferior to that in No. 1.

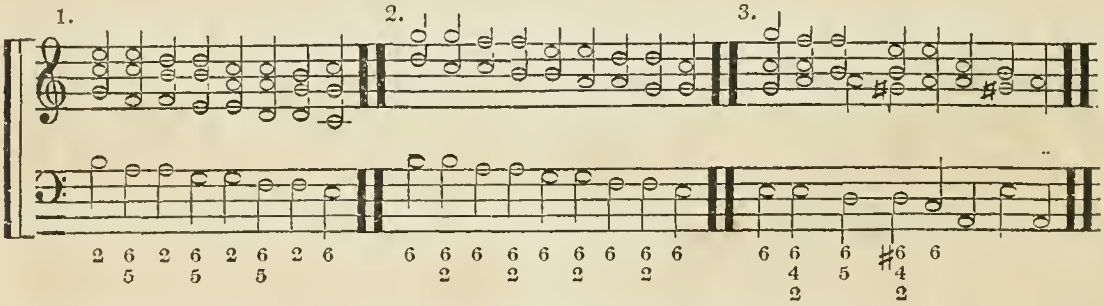


134. In like manner it is not unusual, as Dr. Callcott observes, to follow the chord of the fifth and sixth, with the common chord, instead of the chord of seventh: the example we copy from his Musical Grammar.



135. A more usual inversion of the sequence of seventh, is the alternation of the first and third derivatives on a bass descending by degrees of the scale, as in No. 1. This example is also copied from Mr. Kollmann's thorough bass: but that the reader may not be misled by this or by that in Article 133. 3, he must be told, that though these examples begin with the discord, yet that note is always prepared in the preceding chord. In this progression also, the fifth in the chord of $\begin{smallmatrix}6\\5\end{smallmatrix}$ and the 4th in the $\begin{smallmatrix}6\\4\\2\end{smallmatrix}$ are frequently omitted, so that every second chord becomes a chord of sixth, as No. 2.

In the minor mode, this progression goes very agreeably, on account of the resolution of the subdominant $\begin{smallmatrix}6\\5\end{smallmatrix}$ into the $\begin{smallmatrix}\times 6\\4\\2\end{smallmatrix}$ of the dominant, No. 3.



We shall conclude these examples by observing, that all these chords of the seventh, and their derivatives, which require preparation of the discord, (that is, all except the dominant seventh and its derivatives,) may be very well understood or explained as *suspensions*, which the reader will easily see when we come to treat of that subject. It is as suspensions that these chords are explained by Mon. Choron, and by Mon. Catel. The latter considers as chords properly so called, only such as do not require preparation. These he calls natural chords; and harmony, consisting of such, he calls natural harmony. Artificial harmony is drawn from natural by the suspension of one or more parts prolonged on the time of the succeeding chords. We reckon it, however, a very great advantage to our readers to present the same subject in different points of view. And these chords of the seventh with their derivatives, follow so naturally the analogy of the dominant seventh, (except in the circumstance of requiring preparation,) that an individual acquaintance with them is eaily acquired, and well repays the cost of the acquisition.

CHAP. V.

OF NATURAL TRANSITIONS BY THESE CHORDS.

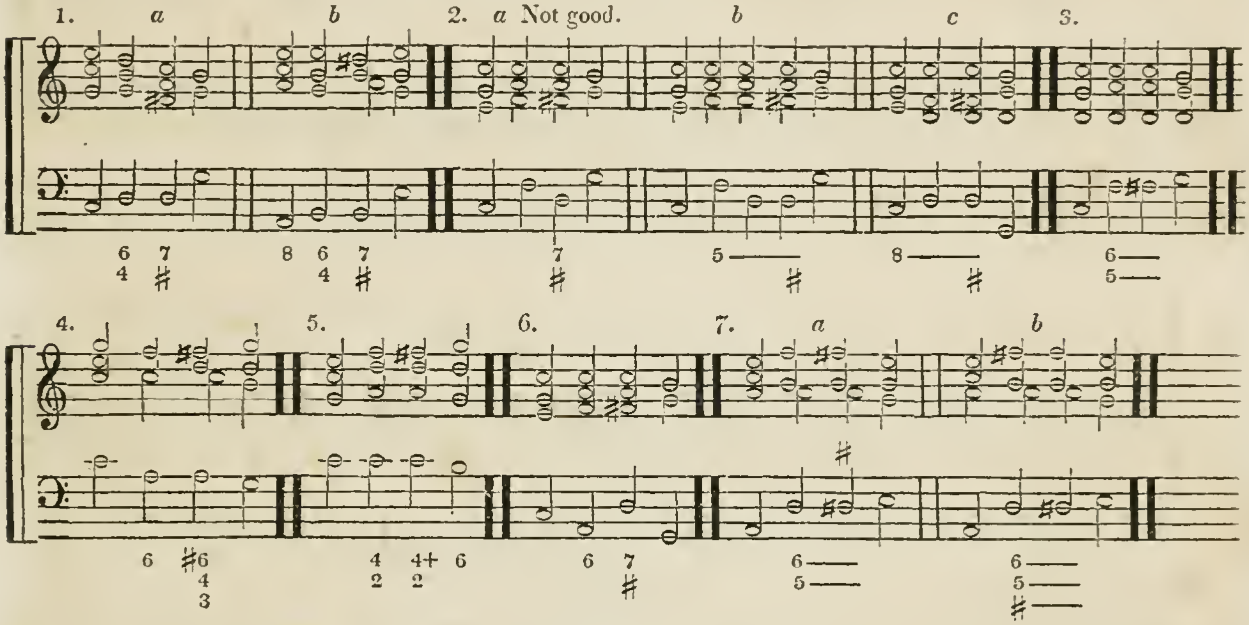
136. Having exhibited pretty fully the mutual connexions of the tonic, dominant, and subdominant harmonies within the key, we shall now proceed to give some specimens passing into the nearest related keys. These are from the major principal key, to the fifth and to the fourth of the key both in the major mode, to the sixth of the key minor mode, called the relative minor, to the second of the key, and to the third of the key, both in the minor mode: From the principal minor key, again, to the fifth and fourth both in the minor, to the third of the key major mode, or relative major, and to the sixth and seventh both in the major. We mean not here to treat the subject of changes in modulation fully,—which requires the knowledge of some other chords not yet treated of; but merely to show how we may pass agreeably from the harmonies of one key to those of another nearly related to it.

137. The most natural and most practised of all changes of key, is to the fifth: and from the tonic harmony to the dominant leading to that new key, we pass in the most natural manner; No. 1, *a*, *b*. We have already remarked, what indeed is very obvious, that in this change the tonic harmony of the principal key is the subdominant common chord on the fourth of the new key. All the examples, therefore, which we have given of the passage from the subdominant harmony to the dominant, are applicable to this change; we shall therefore leave this application to the industry of the reader, without more examples, which would be mere repetition.

We might pass from the subdominant harmony of the principal to the dominant of this new key. To go from the common chord on the 4th of the key to this new dominant 7th, however, as in No. 2, is not very good, because of the false relation crossways, between the note quitted by the bass and the major third of the dominant chord. In general, it is to be observed, that when a note is first heard natural in one chord, and in the next chord the same note is sharpened or flattened, this chromatic change ought to take place in the *same part*, and the octave of the natural note in the first chord ought not to be heard in another part, because of the bad effect of the cross false relation of octave. If, for instance, we follow the common chord of F, with the chord of 7th to D, with minor third, and then change the third chromatically as at *b*, the harshness is quite removed. Or we may take the subdominant seventh on the second of the scale immediately, and then change that chord chromatically to a dominant, as at c. The first inversion of this progression, changing the subdominant 5th and 6th into the dominant small fifth and sixth, goes very agreeably, and is frequently met with, as in No. 3. The second and third inversions, Nos. 4 and 5, are also very good. No. 6, in which the bass leaps to the dominant 7th, is less agreeable than the others.

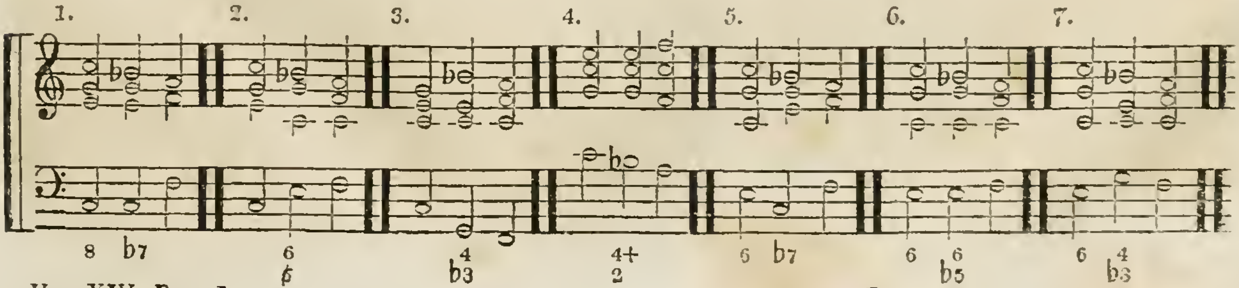
In the minor mode, two parts will move chromatically, No. 7, *a;* or the subdominant harmony may be taken major, as at *b*.

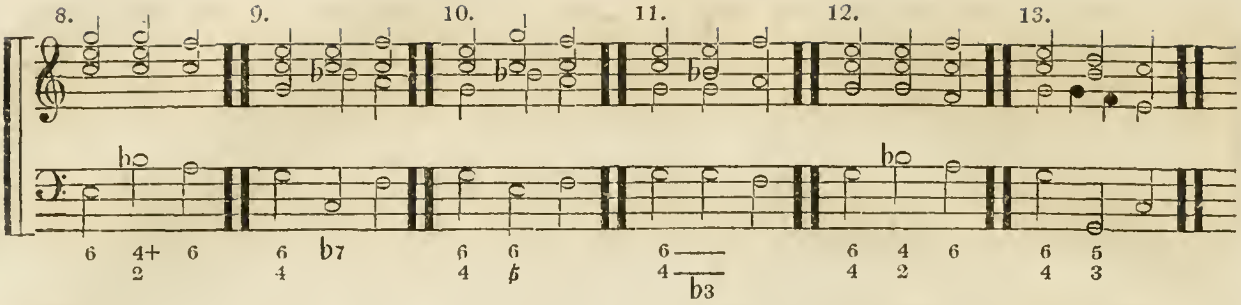
Here we may remark, in passing, that a stroke after a figure, as in these examples, denotes the continuance of the same note in the upper part, even when the movement of the bass changes the interval.



138. To go from the common chord of the principal key to the dominant, leading to the fourth of the key, is only adding a minor seventh to that common chord. The octave succeeded by the minor seventh, is an agreeable and much practised *appoggiatura*, No. 1.

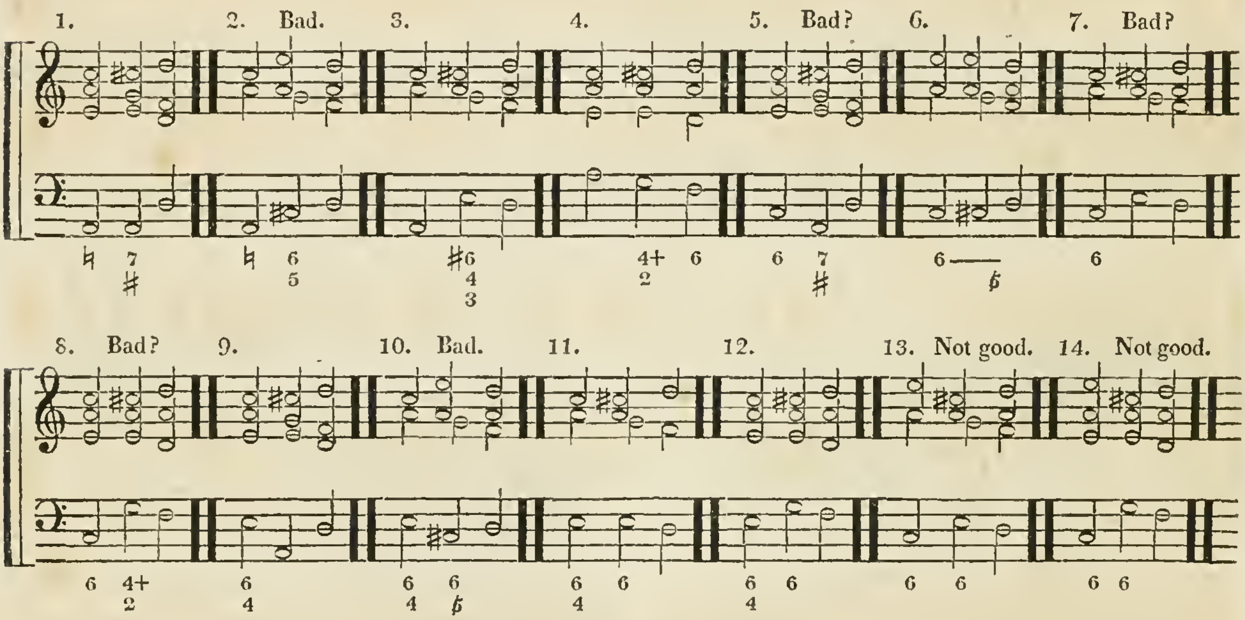
In the major mode, all the derived successions are good, Nos. 2—12. Monsieur Choron observes, that the second without preparation, Nos. 4, 8, 12, is considered as a changed note, that is, that one part takes the place of another, which is always allowed, especially when it is necessary, in order to satisfy some condition, as in fugues, canons, and conditional counterpoints. The four last successions, he observes, are surprises in harmony; for the first chord carrying $\frac{6}{4}$, seems to indicate a close, (in the primary key,) as in No. 13; but the chord of seventh, or its derivatives, succeeding, carries the modulation to the fourth of the key. Of these four successions, No. 9 is the worst. The three others are of good effect.



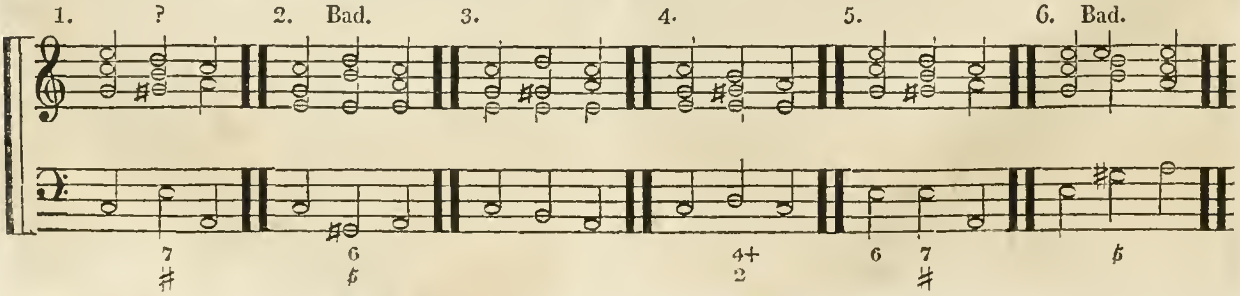


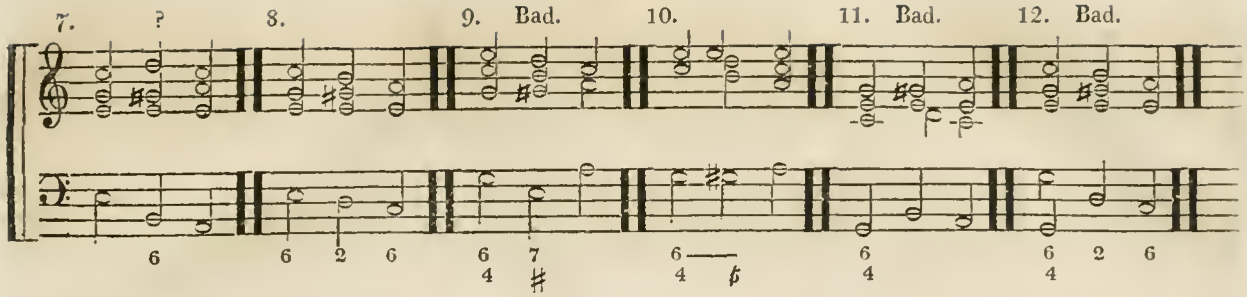
139. In the minor mode, the fundamental progression from the tonic common chord to the dominant seventh, on the same bass, is also very good: but as the third on the tonic chord is minor, care must be taken that the change to the major third take place in the same part. On this account, several of the derived successions become objectionable. Nos. 2, 5, 7, 8, 10, the false relation crossways, in a manner untunes the intervals. Nos. 5, 7, and 8, however, are much less offensive than Nos. 2 and 10; which is attributable in part, at least, to the chromatic movement of the uppermost, which prevents the effect of the false relation crossways from being felt. For if these passages be written as in Nos. 13, 14, the false relation becomes more offensive, though still less so than 2 and 10.

It is plain, that all these examples will, after a modulation into the fifth of the key, conduct back again to the principal.

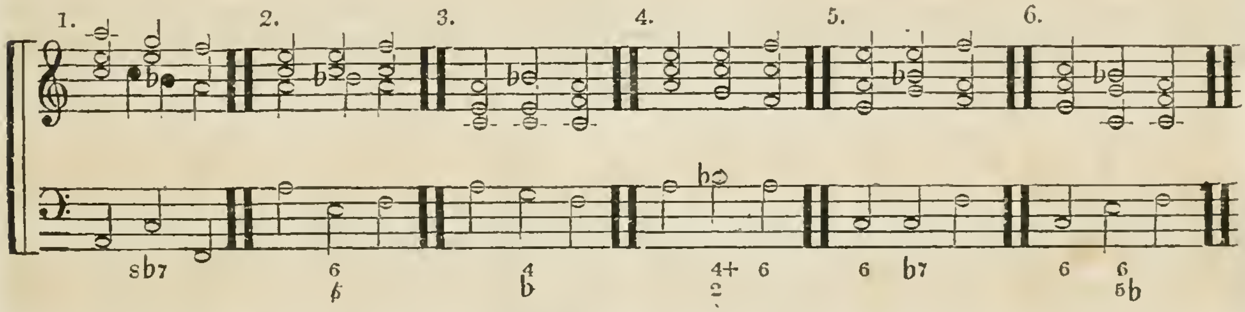


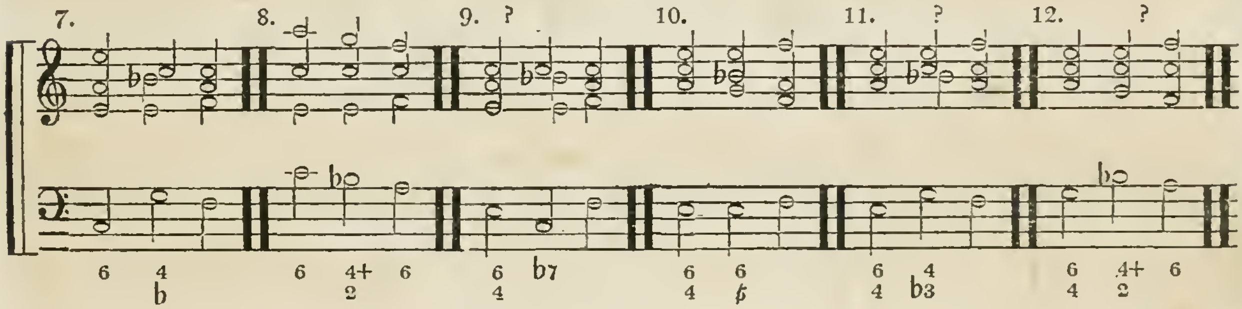
140. To go from the fundamental tonic harmony, major mode, to the dominant seventh, leading to the relative minor, (sixth of the key,) is not very good. There is something sudden and harsh in it. But many of the derivative successions are excellent. These are all given in the examples. Nos. 2, 6, 9, 11, and 12, are to be rejected on account of the false relations of octave, taken crossways. Nos. 3, 4, 5, 8, and 10, are very good, and much in use. In these the bass is stationary, or moves only by single degrees. No. 7, like No. 1, is harsh; and in these the bass leaps several degrees to the next chord. The diatonic movement, except in the case of cadences, says Monsieur Choron, suits always best for the bass. This observation, however, is rather too broadly stated.





141. From the minor tonic harmony, we pass very agreeably to the dominant seventh, leading to the sixth of the key major mode; especially by means of the appoggiatura of the octave, as No. 1. The inverted progressions also are in general good, and in use. The best are still those in which the bass is stationary, or moves diatonically. From the $\frac{6}{4}$ particularly, the leap of the bass, Nos. 9, 11, 12, is sudden and rude. No. 10 is very good.





142. In returning from the relative minor to the relative major, (3d of the former key,) it is rather sudden to go directly from the minor tonic to the dominant; as the two chords have no sound in common. It may, however, be practised by the opposite motion of the parts. We shall copy Monsieur Choron's examples, with his observations. "The greater number of these successions are good, and practised in three as well as four parts. The succession, No. 1, very often takes place in passing from the minor mode to the third of the key major. The succession, No. 2, is employed in the same case. No. 3 is good; No. 4 is sudden, and little used, unless we interpose the G as a passing note. No. 5 does not phrase well. No. 6 is better. No. 7 goes well. No. 8 is harsh. The next four examples are surprises, since the E carrying $\frac{6}{4}$ announces, in general, a close on A, as is seen in the example No. 13.* Nevertheless, they may be employed advantageously; especially Nos. 9, 11, and 12."

The procedure from the tonic minor to the dominant leading to the relative major, may be rendered less sudden by the interposition of the $\frac{6}{4}$, as in No. 14; which is in effect taking the chord of the new key, and thence proceeding to its dominant, sufficiently exemplified in former articles. Or the subdominant of the relative major may prepare the dominant chord, as No. 15; the inversions of which have already been sufficiently explained.

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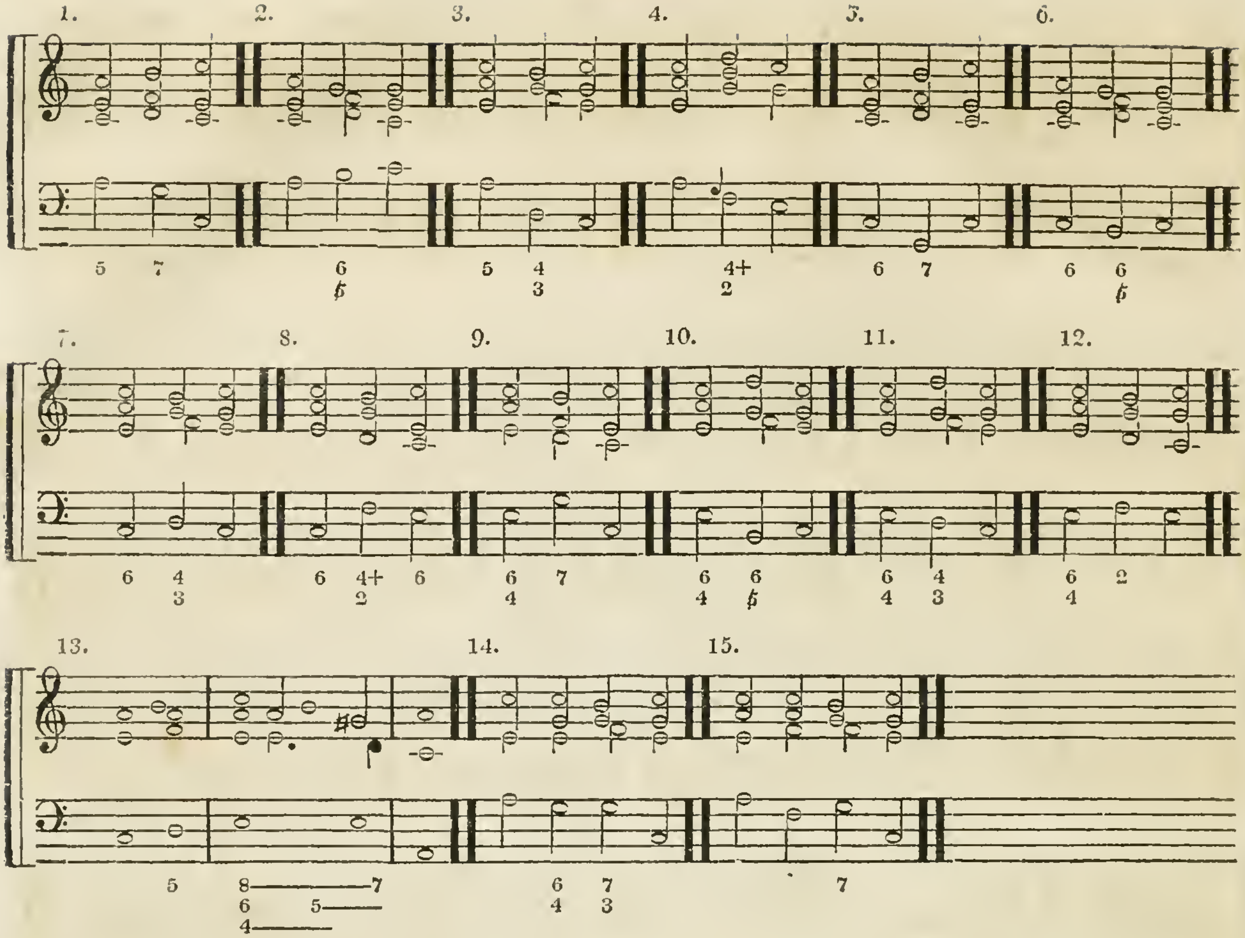
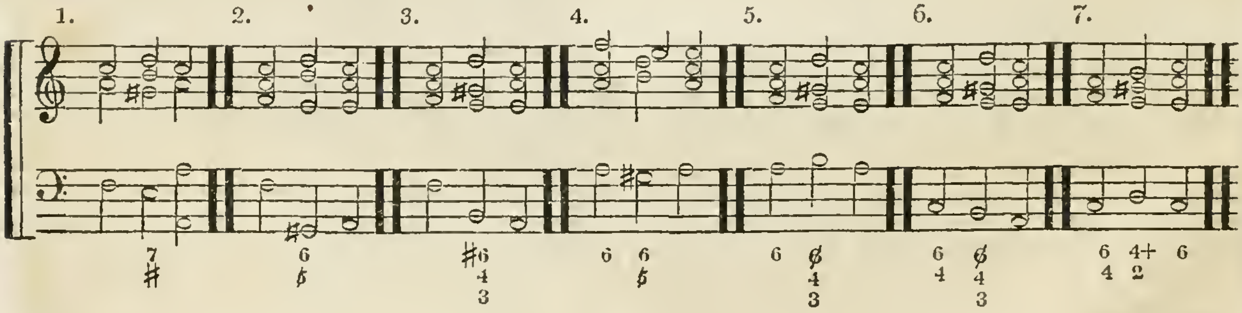
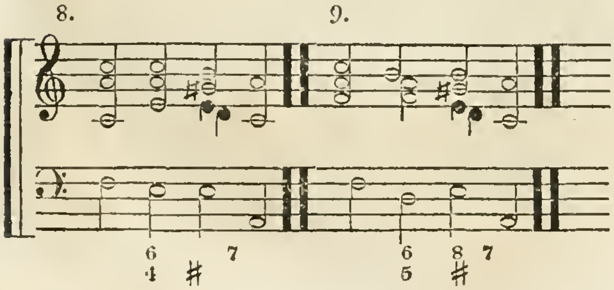
* As we have not as yet given the notation of time or the use of bars, we have in our examples hitherto confined ourselves chiefly to one form of notes, and have used no bars; but we copy M. Choron's example as he has given it. The chord of $\frac{5}{4}$ is a suspension, which of course we have not as yet explained.

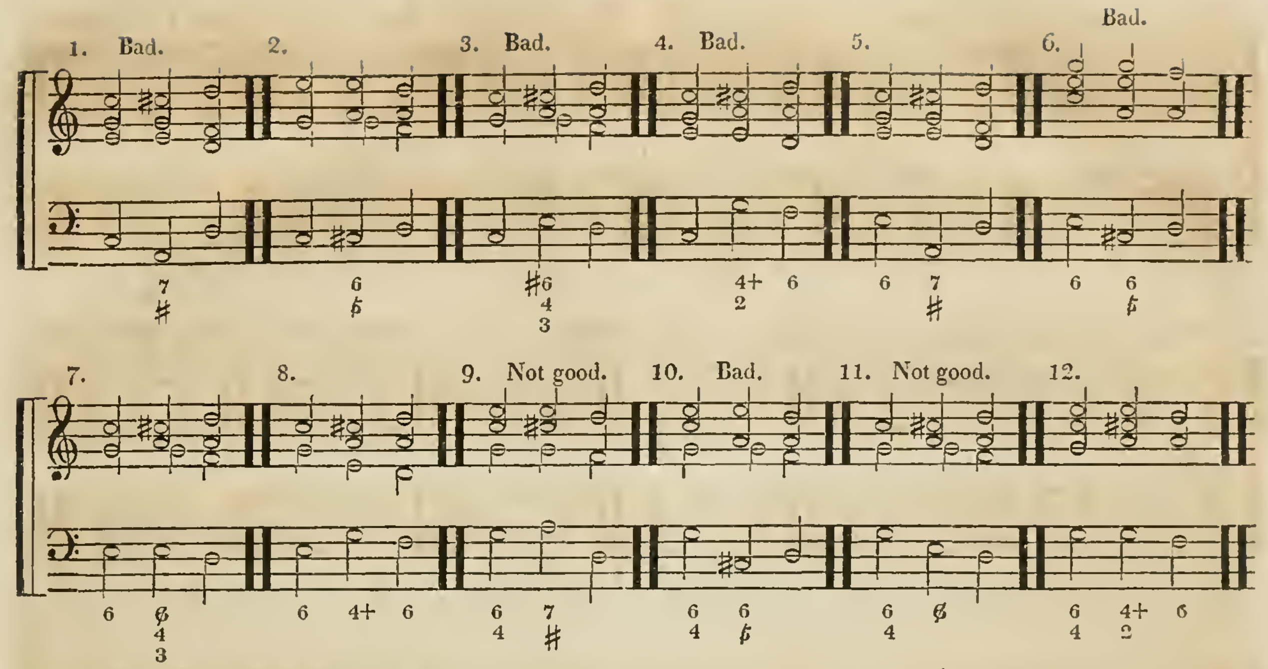


143. In returning from the sixth major mode to the minor principal, the direct procedure from the tonic to the leading chord is still more sudden and less practicable than that in the preceding article. We shall set down from Monsieur Choron only such inversions as have a tolerably good effect, Nos. 1—7. This procedure, like the former, may be softened by the $^6_4$ on the dominant, No. 8; or by interposing the subdominant, as No. 9.

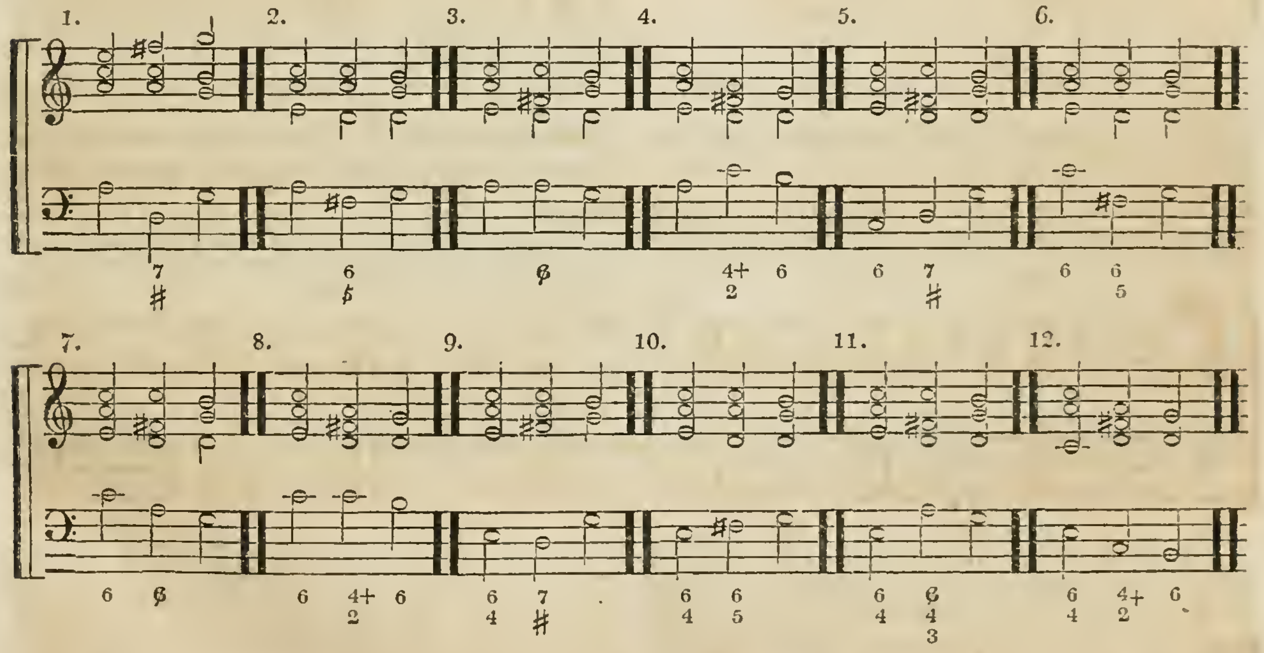




144. From the tonic major we may go directly to the dominant, leading to the second of the key minor mode. The fundamental progression, and several of the derivative become objectionable, on account of the false relations crossways. Of the rest, Nos. 5 and 8 are least pleasing, on account of the leap in the bass. Nos. 10 and 11, in which the $^6_4$ leaps to the leading chord, are still more disagreeable. No. 12 is very good.

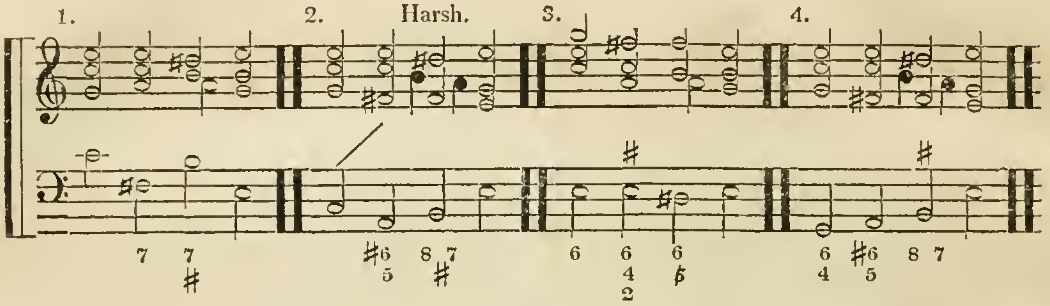


145. The procedure from the minor principal tonic to the dominant leading to the seventh of the key major mode, is very natural and agreeable. Of the derived successions, the least agreeable are those in which the bass leaps several degrees, as Nos. 4, 6, 7. Of the four last, proceeding from the second inversion of the tonic harmony, No. 10 alone is agreeable. The 4th to the bass, we must repeat, leads so strongly to the expectation of a succeeding 3d on the same bass, that any motion in that part, especially a leap, is apt to create disappointment rather than agreeable surprise.

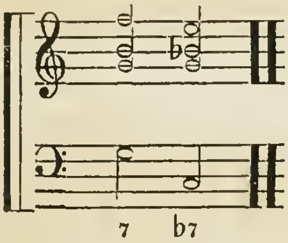


146. It is not very good to go from the major principal to the dominant, leading to its third minor mode. It is the same in effect as the procedure described, Art. 143. But we may go very well from the major chord to the subdominant 7th on the second of the new key, and thence to that dominant, by sequence of sevenths, No. 1. Several of the derived successions are also very good, but we must be careful to avoid bad relations crossways by the movement of different parts. Thus, No. 2 is harsh, on account of the cross relation of greater 4th, as shown by the stroke between the bass and third part. By comparing No. 4, in which the upper parts are exactly the same, and which goes very sweetly, the student will feel the truth of the remark.

We have written all these examples of changes to the nearest related keys in the major mode C, and minor mode of A, as the primary keys; leaving it to the industry of the student to write and perform them in other keys, and to vary the positions of the harmony. These he will find most useful exercises, by means of which the principal parts of harmony in any key will be rendered familiar to him.



147. The dominant chord of seventh, instead of resolving on a common chord major or minor, or on a chord of the seventh, such as is furnished by the scale of the key we are in, as in the diatonic sequence of sevenths, frequently resolves on another dominant seventh. In this case, the major third, or leading note, instead of ascending *diatonic* semitone, to the resolution, or remaining in its place to prepare the succeeding seventh, descends *chromatic* semitone, to become minor seventh in the second dominant. The seventh resolves as usual by diatonic semitone on the third of the new dominant.



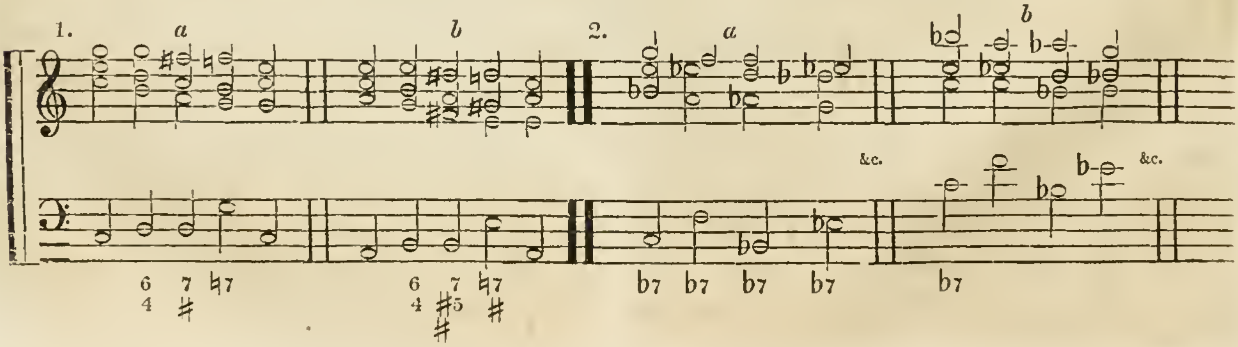
148. Here we may explain, in passing, that the two semitones in the diatonic scale, between the major third and minor or perfect fourth, and between the major seventh and octave, are called diatonic semitones; whereas the difference between a major and minor interval, as between major and minor third, major and minor fifth, major and minor seventh, &c. are called chromatic semitones. On keyed instruments in general, these two kinds of semitone are equal, or at least not distinguished; yet it is of great importance in writing, even for keyed instruments, to distinguish them, in order to write correctly. The reader, in the mean time, may distinguish them by this, that the two sounds, differing by diatonic semitone, have different *names*, as EF, BC, F※G, G※A, &c.; but the two sounds, differing by chromatic semitone, have the same name, only one of them has a ※, ♭, or ♮; as BB♭, CC※, F※, F♮, &c.

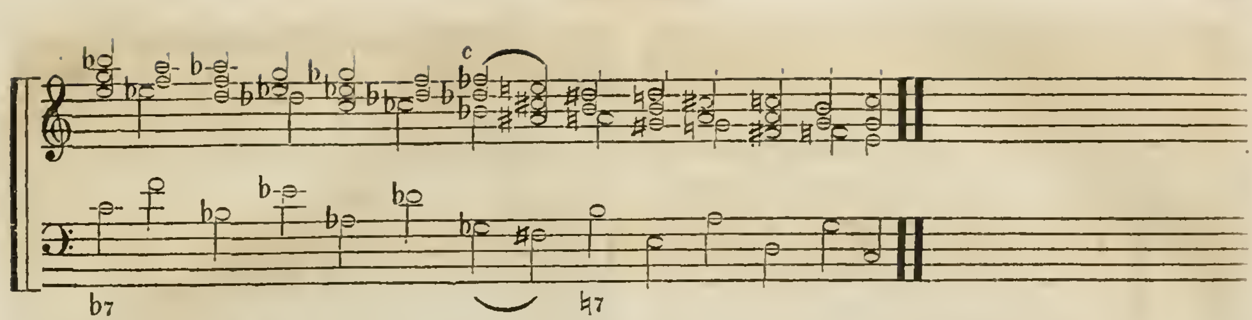
On instruments capable of being tuned perfectly, these two kinds of semitone differ very considerably. Thus, if we tune major third and minor third to C, the E and E♭ differ by chromatic semitone. Now, if we make E a key-note, and take D※ as major third to B, (perfect fifth to E,) this D※ will be diatonic semitone below E, and will be found to be very considerably flatter than E♭. This difference, as we have elsewhere said, is called the *enharmonic fourth of the tone*, or the *enharmonic diesis*.

We shall afterwards find, that there are even two different chromatic semitones, and two enharmonic dieses; but we shall not perplex the student with these at present. To return to the sequence of dominants.

149. In consequence of this second dominant, a change takes place in the modulation, the resolution into the common chord being avoided. The French call this succession *Evitation de la cadence parfaite*. We call it a sequence of dominants. This sequence is very often practised in coming to a close on the primary key, by taking a dominant chord of 7th on the second of the scale instead of the subdominant chord of seventh, both in the major and minor modes, No. 1, *a*, *b*.

If there be only two dominants in the sequence, as in these two examples, the passage may be in four different positions, according as the first dominant may be written. But if the sequence consist of many chords, we shall find that they come to two principal positions only, viz. the fifth and octave of the chords alternately highest, No. 2, *a;* or the minor 7th and major 3d alternately highest, *b*, *c*. This last position is given in two forms, one a little more dispersed, and the other closer. The octave and fifth are omitted alternately.

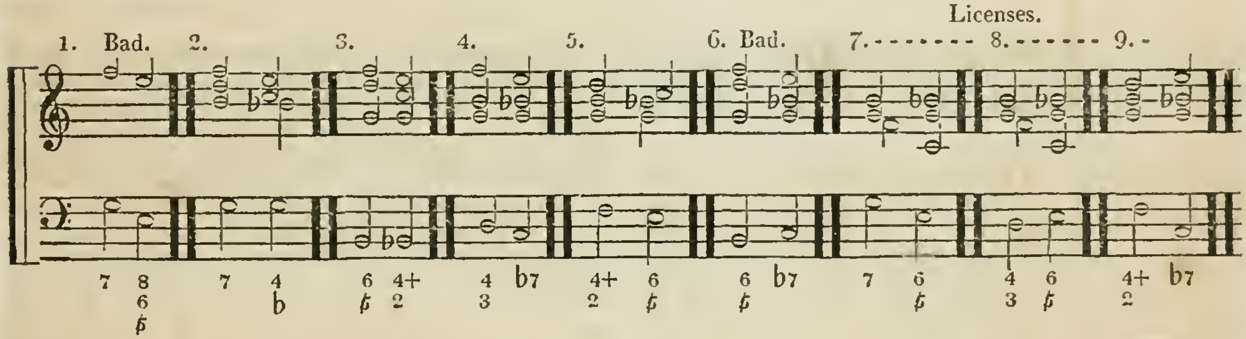


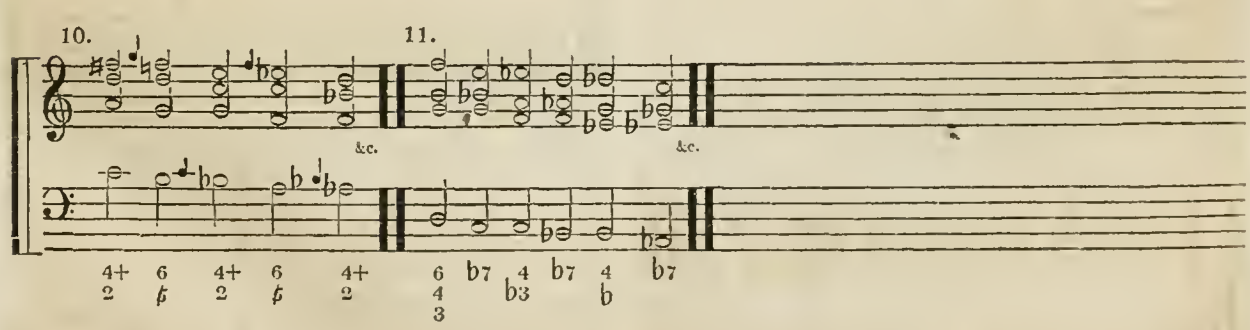


The last example *c*, makes what is called the Tour of the key-board, *Tour du clavier*. The descent by fifth, and ascent by fourth, alternately in the bass, introduces an additional flat each step, till we arrive at the dominant seventh on G♭, viz. G♭, B♭, D♭, F♭; but these notes, as far as regards keyed instruments, being the same with F𝄪, A𝄪, C𝄪, E♮, the chord is written both ways, (and need not be repeated in the performance.) Thence proceeding as before, every step removes a sharp till we arrive at C, whence we set out. Compare Art. 80—84.

In this progression, two parts descend by diatonic and chromatic semitones alternately, which is called a chromatic descent, being in the degrees of that scale; and such passages seem to be exclusively called chromatic by Dr. Burney. "It is only a regular succession of two or more *semitones* ascending or descending, that constitutes *modern chromatic*."—*Hist. Mus.* vol. i. p. 29. Note.

150. From the number of real parts in each chord, we might easily suppose the derived progressions to be very numerous. Two circumstances, however, tend to circumscribe their number. 1st. The chromatic difference, between the sensible note in one chord, and the discord in the next, must not be found in different parts, on account of the false cross relation of octaves. Thus No. 6 is bad, because of the false relation between the bass of the first chord and the 7th in the second chord. The chromatic descent must be in the same part, therefore the chord of $\genfrac{}{}{0pt}{}{6}{\natural}$ can only be followed by that of $\genfrac{}{}{0pt}{}{4+}{2}$, nor can this last be brought in but as following the $\genfrac{}{}{0pt}{}{6}{\natural}$. 2dly. The resolution of the discord tends to limit the number of admissible successions. Thus No. 1 is bad, because the resolution of the 7th on the 8 is felt like consecutive octaves. For the same reason, the $\genfrac{}{}{0pt}{}{4}{3}$ cannot well be followed by the $\genfrac{}{}{0pt}{}{6}{\natural}$, except by license, as in No. 8. The only regular successions derived from the sequence of dominants, seem to be Nos. 2, 3, 4, 5. Nos. 7, 8, 9, are licenses in the resolution of the discord, as described in Art. 121, No. 14, *c, d*.





The four derived successions furnish two sequences or progressions, which, like the fundamental, may be continued at pleasure. The first is the chord of $\genfrac{}{}{0pt}{}{4+}{2}$ and that of $\genfrac{}{}{0pt}{}{6}{\natural}$ alternately, No. 10. Mr. Shield observes, that without the appoggiaturas, the highest note of the sharp [major] fourth, and the lowest of the false fifth, would fall, contrary to the general rule, and render the progression extremely harsh. The second is the dominant seventh, and the second derivative $\begin{smallmatrix}6\\4\\3\end{smallmatrix}$ alternately, No. 11.

CHAP. VI.

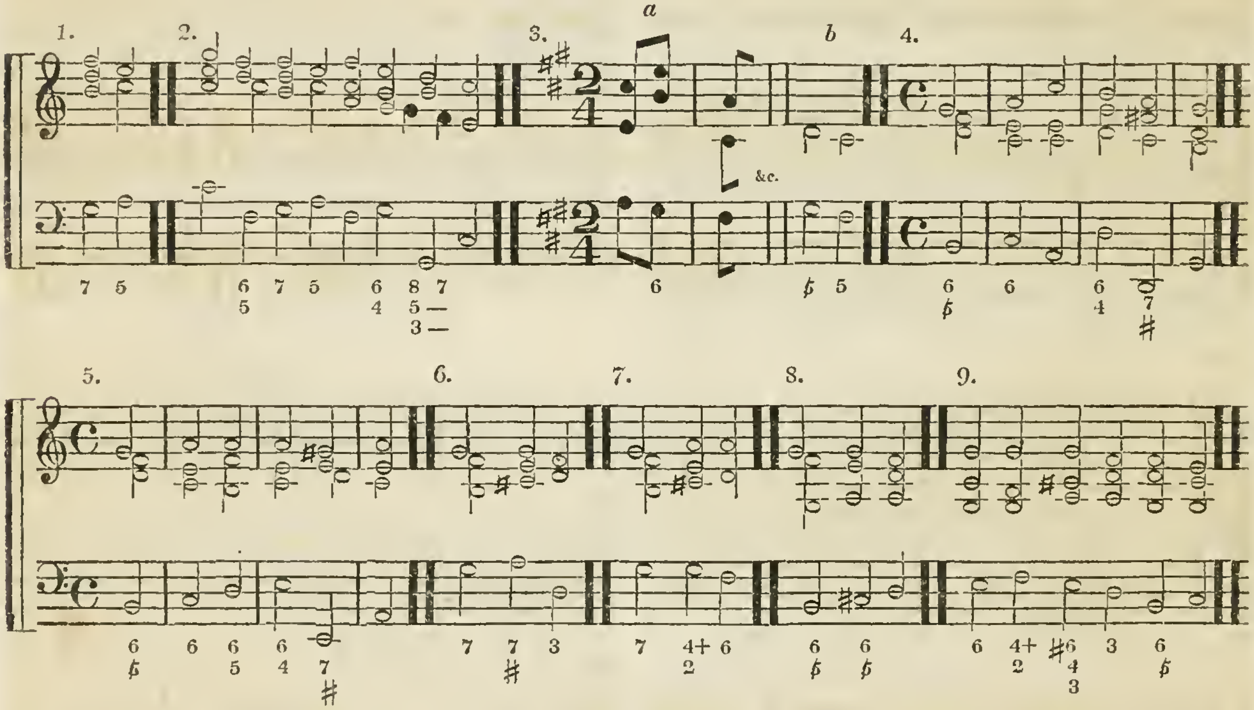
OF THE RESOLUTION OF CHORDS OF THE SEVENTH BY THE DIATONIC ASCENT OF THE BASS.

OF THE SEVENTH ON THE SENSIBLE NOTE, AND THE MAJOR NINTH ADDED TO THE DOMINANT CHORD.

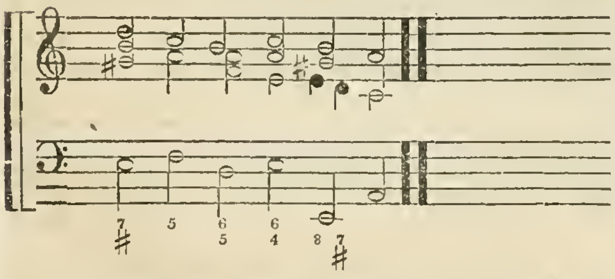
OF THE CHORD OF DIMINISHED SEVENTH, AND THE MINOR NINTH ADDED TO THE DOMINANT CHORD.

151. Hitherto we have exhibited the resolution of chords of the seventh only in one way, viz. by descent of the bass by fifth, or ascent by fourth, to the fundamental note of the chord on which the seventh resolves. We are now to show resolutions of these chords by other fundamental progressions. We begin with the dominant seventh.

We have observed, Art. 121, that in the chord of dominant 7th, what most forcibly attracts the ear, is the imperfect fifth, between the major third and minor seventh of the chord; and that the resolution of this interval is by the rise of the lowest note semitone, and by the diatonic descent of the highest, the parts meeting on a third major or minor according to the mode. Now if in the dominant of the major principal, this small fifth be resolved on a major third, and if the bass (instead of ascending 4th) ascend a tone to the sixth of the key, the interval of seventh will be resolved on the perfect fifth, and we shall have the chord of the relative minor instead of the major principle tonic; No. 1. This resolution taking place on the proper part of the measure, forms a *broken cadence*, or *suspended cadence;* and this indeed is the way in which this progression is chiefly used, being substituted for the perfect cadence, where the strain might be expected to end, but is thus interrupted, and the final close takes place afterwards. No. 2 exhibits the outline of such a close, first interrupted or kept in suspense by the resolution on the chord of the relative minor, and then closing fully on the key.



10.



This progression is very seldom if ever inverted. Mozart begins a much admired duet with the first inversion of the common chord of the fifth of the key going to the relative minor, No. 3, *a*, which is this broken cadence without the discord. But it is plain that here the discord is inadmissible from the motion of the bass, as the lesser fifth would be followed by perfect fifth, as at *b*. For though an imperfect fifth may sometimes be followed by a perfect fifth, yet here it would be bad, as disappointing the resolution of the 7th. Monsieur Choron says, that one or two of the inversions, though little used, because they do not phrase well, are yet susceptible of being so; and he says they seem to indicate modulation to the fifth or to the sixth of the key. We shall give only one of these inversions, the $\frac{6}{5}$ resolving on the chord of 6, with the way in which he makes it conduct to these two keys, Nos. 4, 5. The resolution in question is of the first chord on the second in each example.

The chord on which the dominant resolves by the ascent of tone, may be a dominant chord of seventh, thus conducting the modulation to the second of the key. Nos. 6, 7, 8, 9, show this resolution with its derivatives. They are taken from M. Choron. The last brings the modulation back to the principal key.

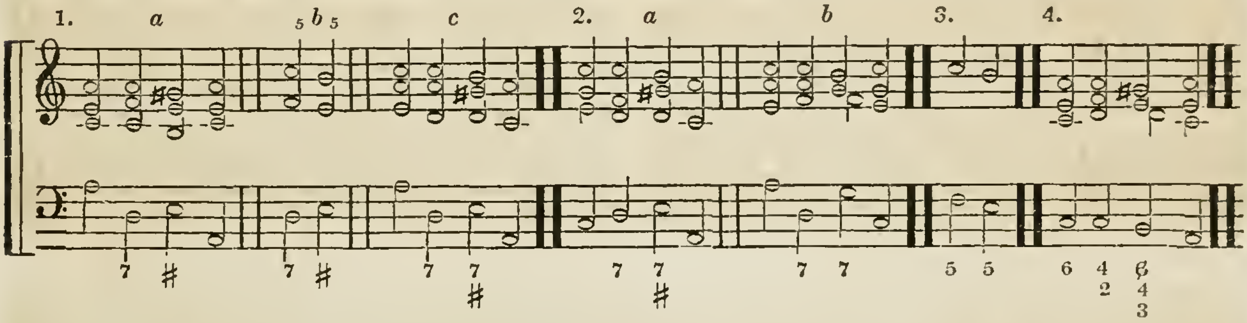
If in the dominant 7th of the minor key the ♭th resolve on a minor third, and the bass rise semitone, the 7th will resolve on the major chord of the 6th of the key, No. 10; and this is used as an interrupted cadence in the same way as the preceding in the major mode. The inversions of this progression are not in use.

152. This manner of resolving the chord by the diatonic rise of the bass, is also practised in the other chords of the seventh.

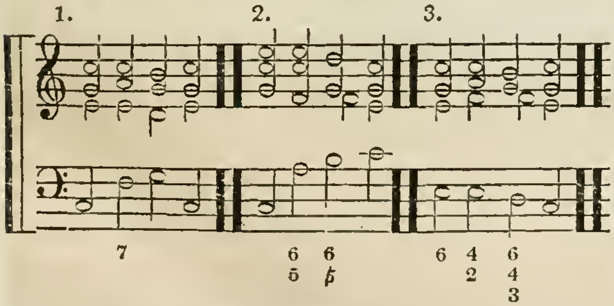
The minor seventh, with minor third on the 4th of the minor key, is very often resolved by the diatonic ascent of the bass on the leading chord, as in No. 1, *a*. If the 7th of the chord be higher than the third, we must be careful to avoid consecutive fifths, which would take place if we should take the C an octave higher, as at *b*. In such a case the third may be omitted, and the octave taken in its stead, as at *c*.

The seventh in question, then, is another subdominant chord in the minor mode; to which we have thus two subdominant 7ths, that on the second of the key with imperfect fifth resolving by descent of fifth in the bass on the dominant chord; and this on the fourth of the key resolving by ascent of major second on the same dominant. Now, this last subdominant 7th on the fourth of the minor, is the very same of which we have treated as subdominant 7th on the second of the major key, Art. 127 and 128. This subdominant chord, therefore, is one link of connexion between these two relatives, and may easily lead from the one to the other, as in No. 2, *a*, *b*. In the former of these examples, we have avoided the fifths noticed at No. 1, *b*, by making the minor third of the subdominant seventh ascend by redundant second to the major third of the dominant chord,—a movement which some censure as licentious, but which may be found frequently exemplified in the writings of the best masters.

This resolution of the minor seventh with minor third, by the diatonic rise of the bass on the leading chord, is hardly capable of being inverted. The first derivative, viz. the $^{6}_{5}$ on the sixth of the minor scale, cannot resolve on the fundamental dominant chord, because of the consecutive fifths which would arise from the resolution of the discord, No. 3. The second inversion is impracticable; but the third inversion, resolving on the second inversion of the dominant, No. 4, appears to us to go well, and indeed to be of as good effect as the fundamental progression. We do not recollect to have seen it used.



153. After the same manner, the chord of major seventh resolves by diatonic ascent of the bass on the dominant of the major key, being thus another kind of subdominant seventh on the 4th of the key, No. 1. Here again we must guard the student against consecutive fifths, into which the resolution of the 7th on the 5th of the dominant chord might betray him. For if the part next the bass in the example, were written an octave higher, there would be fifths, (which are here fourths,) between that part so put highest, and the second part. See Art. 152, No. 1, *b*.



Dr. Callcott gives, in his Musical Grammar, the example, No. 2, of the first derivative of the major seventh resolving on the first derivative of the dominant, which he calls a partial sequence of two similar harmonies (as he justly observes) frequently found in Handel. The third inversion, resolving on the second inversion of the dominant, though we do not recollect to have met with it, appears to us to be equally practicable with either of the preceding, No. 3.

We have thus in either mode, two fundamental subdominant chords of the seventh, resolving on the dominant chord. In the major mode, the minor seventh on the second of the key, of which the first derivative, viz. the $^{6}_{5}$ on the fourth of the key, is most frequently practised; but whose third derivative, resolving on the $^{6}_{\not 5}$ of the dominant, is also of very good effect; and the major seventh on the fourth of the key, of which two derivatives seem also practicable. In the minor mode again, the minor seventh, with imperfect fifth on the second of the scale, of which also the $^{6}_{5}$ on the fourth of the scale is most practised, but whose third derivative, viz. $^{4}_{2}$ on the key-note, resolving on the dominant $^{6}_{\not 5}$ on the sensible note, is also in use; and the minor seventh on the fourth of the scale, treated of Art. 152, of which the third derivative, resolving on the second inversion of the dominant, seems also practicable.

154. The minor seventh, with minor third and imperfect fifth, may also resolve by the diatonic ascent of the bass on the major common chord, No. 1, *a*. *b*. The bass then is the leading note which ascends to the key-note; the $\not 5$ is the discord of the dominant, which resolves diatonically downwards on the third of the key; and the seventh resolves diatonically downwards on the fifth of the key. Of four parts, then, of which the chord consists, three have a determined movement; and when the chord is in the position *a*, the third also must ascend to the third of the tonic; for, if it should descend to the key-note, there would be consecutive

perfect fifths. If the chord be in the position at *b*, then the 3d may descend on the octave, and the three upper parts will proceed like a descending sequence of sixes. The third of the chord, however, is generally omitted, to diminish the harshness.

This chord of minor seventh with imperfect fifth, may thus either belong to the minor mode, being the subdominant chord on the second of the scale, or it may belong to the major mode, being a chord of seventh on the seventh of the scale, or sensible note. When it is to be thus resolved, therefore, the bass note ought not to be doubled, nor the fifth, which is the dominant discord.

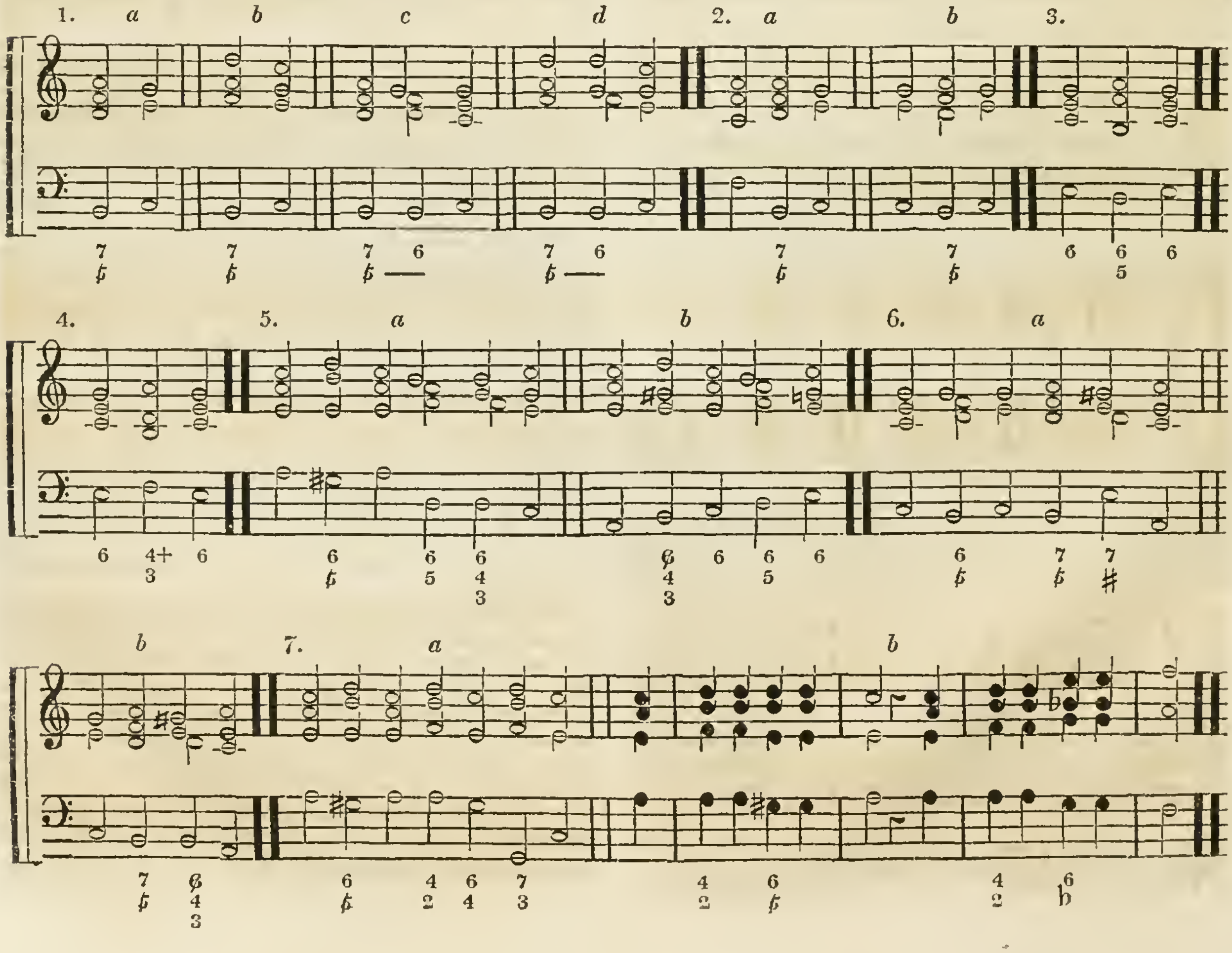
This chord, in proceeding to the major common chord, frequently resolves, in the first instance, into the $\begin{smallmatrix}6\\ \flat\end{smallmatrix}$ on the same bass, that is to say, into the first inversion of the dominant seventh on the fifth of the key, as at *c*, *d*.

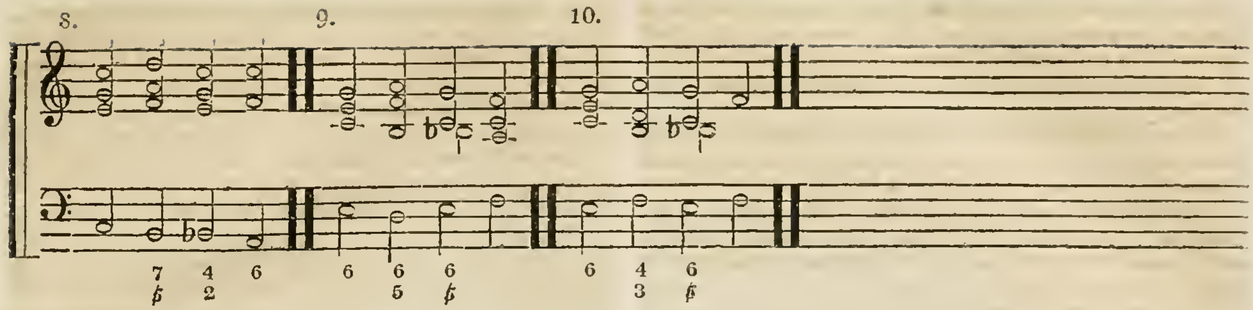
This chord is used either with or without preparation. In No. 2, *a*, it is prepared in the subdominant chord, and at *b* it follows the tonic harmony without preparation. These examples are taken from Callcott's Grammar.

This progression may be inverted. Mon. Choron lays it down as a rule, that the original bass, and the seventh of the fundamental chord, be still kept at the distance of seventh. Nos. 3 and 4 are his examples. But this rule must be restricted to the case when the discord (seventh of the original chord) is not prepared. For, if the discord be prepared, we do not see what should prevent its being at the distance of a second more than in the subdominant of the relative minor. Thus the subdominant $\begin{smallmatrix}6\\ 5\end{smallmatrix}$ of the minor key, No. 5, *a*, may be made to resolve into the second derivative of the dominant of the relative major; or directly into the first derivative of the tonic relative major, as at *b*. On the other hand, the rule which he gives that this chord of seventh must be prepared when taken on the second of the minor scale, (which we have called the subdominant seventh,) may be disregarded when the discord is kept at this distance of seventh. Thus the chord of seventh on the leading note of the major key, taken without preparation, may be resolved into the dominant of the relative minor or its second inversion, No. 6, *a*, *b*.

Mon. Choron also says, that the third inversion of this chord, when the discord is put in the bass, is inadmissible in any manner. But this means only that it is inadmissible without preparation. In No. 7, *a*, this chord, prepared in the key of A minor, as if the third inversion of the subdominant seventh on the second of the scale, is resolved into the second inversion of the chord of the relative major, or $\begin{smallmatrix}6\\ 4\end{smallmatrix}$ suspending its dominant. The example at *b* is taken from Shield's Introduction to Harmony, in which that excellent master treats the chord in both ways: it is first resolved, as a subdominant chord on the dominant of A, the primary key, and then it is resolved on the second inversion of the chord of C, made a dominant chord, only that the fourth is omitted, so that the chord appears as chord of sixth on the second of the key of F. Thus the modulation passes to the sixth of the primary key.

This minor seventh, with imperfect fifth may, by the chromatic descent of the bass, become the third derivative of the chord of dominant seventh, No. 8; which is analogous to the derivative succession of the sequence of dominants, Art. 150. No. 3. And this may be inverted as in Nos. 9 and 10. These three examples are taken from Choron.





155. The two dominant chords of seventh, viz. that on the fifth of the key, and this on the leading note of which we have been treating, are united into one chord, and the union forms a chord of minor seventh and major ninth on the fifth of the scale, or, in other words, a major ninth added to the dominant chord of seventh; No. 1. In this combination the intervals must be taken in a regular order; the ninth must be at the real distance of ninth, and not of second from the bass or its octave, and of seventh from the third of the chord, (sensible note,) at least if used without preparation. The ninth resolves on the fifth of the succeeding tonic, and the rest of the chord as the dominant seventh, only that the fifth, if under the ninth, must not fall on the octave of the tonic, on account of the fifths, as shown in the preceding article. The fifth of the chord is generally omitted, to diminish the harshness of the combination.

It is easy to see what this addition of the major ninth to the dominant seventh will produce, in the derivatives of that chord.

To the first derivative of the dominant seventh it adds a minor seventh, and the whole chord may be figured $\begin{smallmatrix}7\\6\\5\end{smallmatrix}$. When the new discord is unprepared, it must still be at the distance of ninth from the fundamental note, or fifth of the key. No. 2.

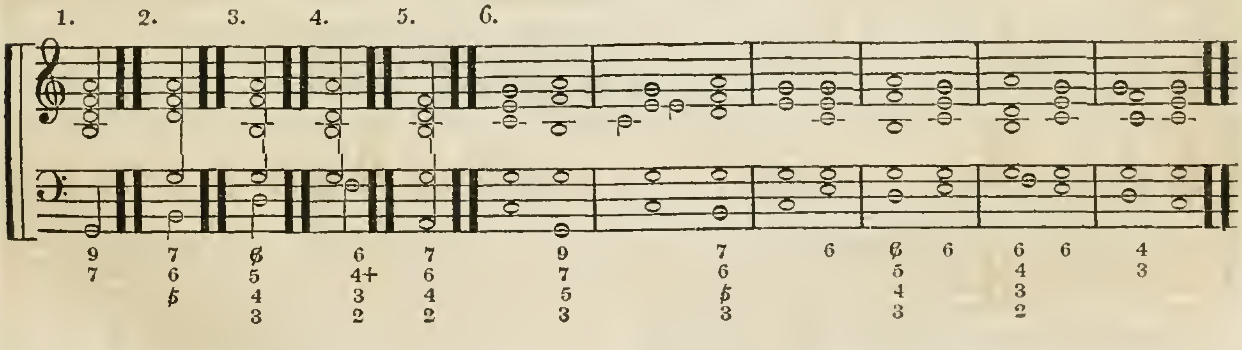
To the second derivative of the dominant seventh it adds a fifth, which, if unprepared, must be at the distance of ninth from the fourth or fundamental sound. The whole will therefore be figured $\begin{smallmatrix}6\\5\\4\\3\end{smallmatrix}$. No. 3.

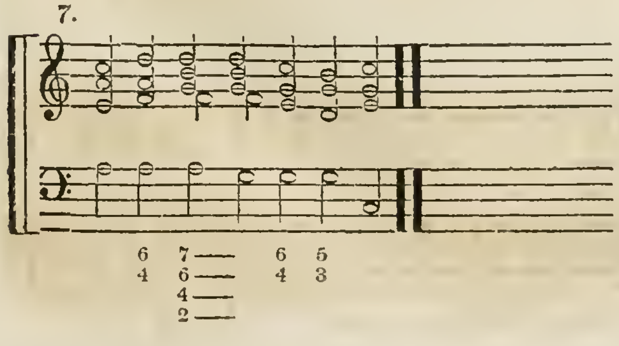
To the third inversion of the dominant seventh it adds a major third, and this third ought to be at the distance of ninth from the second of the chord or its octave, at least if unprepared. The chord will be $\begin{smallmatrix}6\\4+\\3\\2\end{smallmatrix}$. No. 4.

Lastly, when this new discord is in the bass, all the intervals of the dominant chord appear under new figures; the third becomes second to the new bass, the fifth becomes fourth, the seventh becomes sixth, and the fundamental sound seventh. The whole chord is $\begin{smallmatrix}7\\6\\4\\2\end{smallmatrix}$. This chord is never used without being prepared in the bass.

As the reader can be at no loss to understand this chord from what we have said of the $\begin{smallmatrix}7\\♮\end{smallmatrix}$ on the leading note, we shall be contented with giving Mon. Choron's general example of it, and its inversions, as following the tonic harmony and returning to it. No. 6.

The only one of the derivatives which Mon. Choron has omitted, is that in which the discord is put in the bass, because, needing preparation, it does not come under his definition of a simple chord. We shall therefore give one example of it, as leading from the minor mode to the relative major, No. 7.





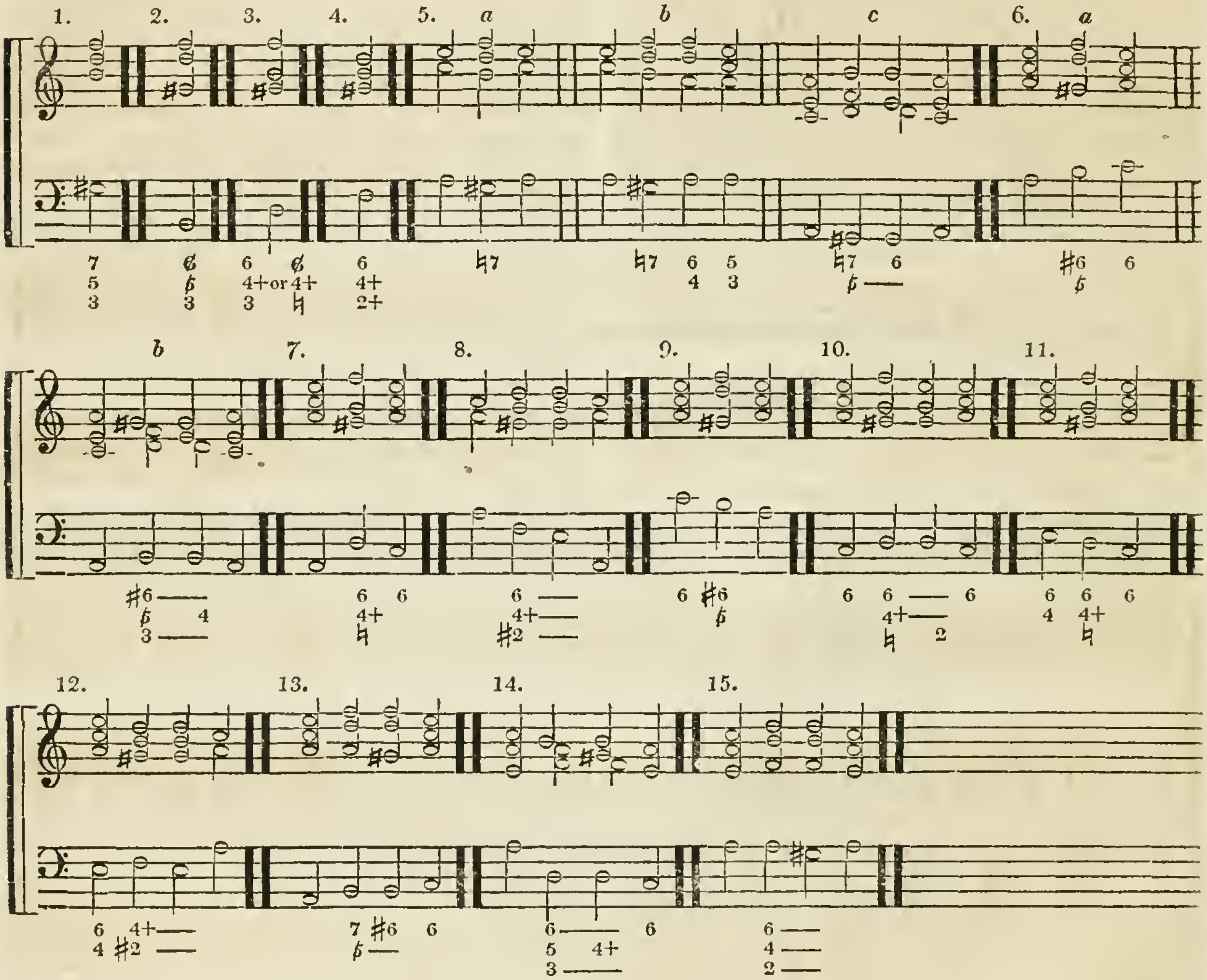
156. We have already taken notice of the interval from the minor sixth of the scale, minor mode, to the seventh of that scale, made major by the accidental sharp. This is called an *extreme sharp second*, or *redundant second*. It consists of a tone and a chromatic semitone. On keyed instruments it is played by the same finger-keys which give a minor third, but the latter interval consists of a tone and diatonic semitone; and therefore the redundant second and minor third differ by the diesis, or about the fourth of a tone, the minor third being so much the greater interval of the two. See Art. 148.

This redundant second, inverted, gives a species of seventh different from those we have hitherto treated of. It is called the diminished seventh; it is chromatic semitone flatter than the minor seventh, and enharmonic diesis or fourth of a tone sharper than the major sixth.

This interval, the redundant second, and its inversion the diminished seventh, are of very great importance in modern music.

157. If to the imperfect fifth on the leading note of the minor key, (*i. e.* the seventh of the scale accidentally sharpened,) we add its seventh as it lies in the scale; we have the chord of diminished seventh. It consists, therefore, of minor third, imperfect fifth, and diminished seventh, and is figured $\flat\begin{smallmatrix}7\\ \not{5}\\ 3\end{smallmatrix}$, or simply ♭7, or without the character of flat, where the seventh as it lies in the scale is diminished 7th to the bass, though even then it is proper to signify it by a ♮7. All the inversions of this chord are used; and we exhibit these chords, Nos. 1, 2, 3, 4.

The first inversion consists of minor third, imperfect fifth, and major sixth. It is figured $\begin{smallmatrix}\not{6}\\ \not{5}\\ 3\end{smallmatrix}$, or $\not{6}$, the third being understood; and it is proper to signify the nature of the fifth, which is the discord, thus $\not{5}$, even though the imperfect fifth to the bass be in the scale.



The second inversion consists of minor third, major fourth, and major sixth figured $\begin{smallmatrix}6\\ 4+\\ 3\end{smallmatrix}$ or more properly $\begin{smallmatrix}6\\ 4+\\ \natural\end{smallmatrix}$ or $\begin{smallmatrix}6\\ 4+\\ \flat\end{smallmatrix}$ the natural or the flat signifying the minor third to the bass, which third is the discord.

The third inversion consists of redundant second, greater fourth, and great sixth, figured $\begin{smallmatrix}4+\\ 2+\end{smallmatrix}$ or $\begin{smallmatrix}4+\\ \not{2}\end{smallmatrix}$ the dash through the 2 signifying that it is taken sharp.

These chords are of much more frequent use, of much more importance, and will require a much more extensive examination than the chord of seventh on the leading note of the major scale.

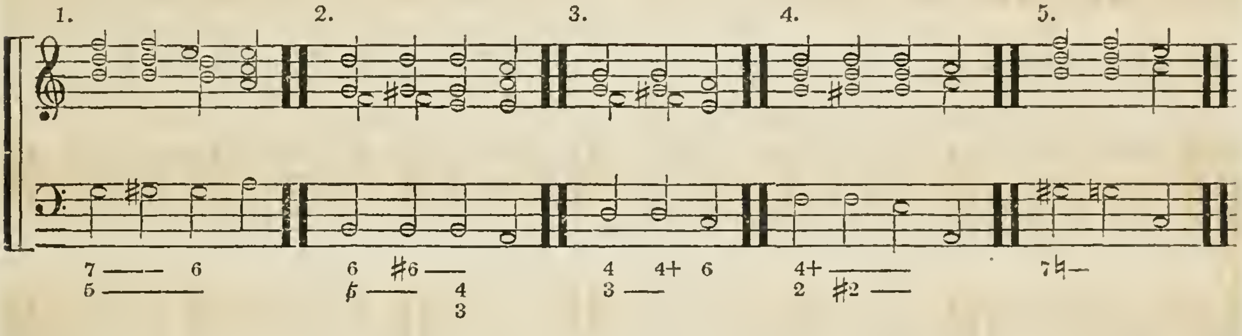
In the chord of the diminished seventh the bass is the sensible note, which therefore ascends semitone to the tonic; the fifth is the discord of the dominant chord on the fifth of the key, which therefore descends to the third of the tonic; the diminished seventh in like manner descends on the fifth; the third of the chord is the fifth in the dominant chord, and therefore may either ascend to the third, or descend to the tonic; the former is better when the diminished seventh is higher than third of the chord on account of the fifths in the succession. Yet this is not so necessary to be guarded against as in the resolution of the other chords of the seventh, by diatonic rise of the bass, as the first fifth is imperfect.

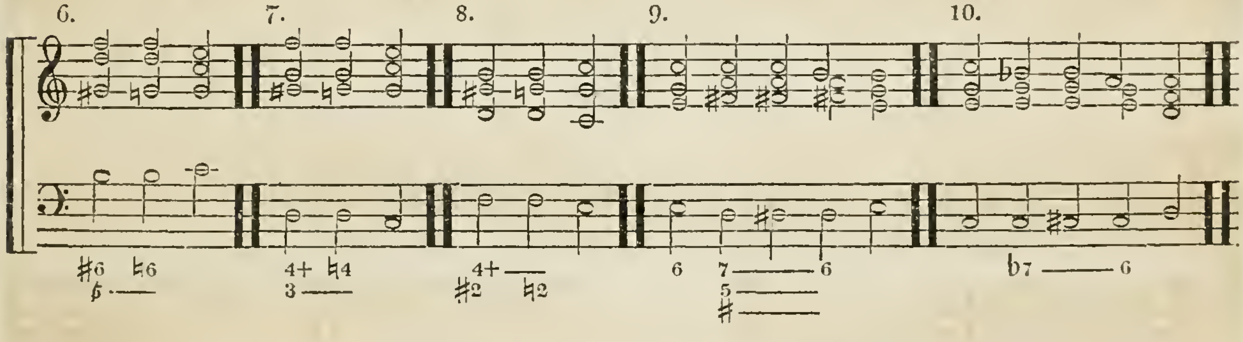
The diminished seventh, and all its inversions, are used with or without preparation.

No. 5, *a*, shows the chord of diminished seventh taken without preparation after the minor tonic harmony, and returning to the same. The resolution into the tonic is often retarded by the $^{6}_{4}$ on the tonic bass, as at *b*. The diminished seventh also frequently resolves on the $^{6}_{\not 5}$ first derivative of the dominant chord, as at *c*. And this resolution into the proper dominant of the same key, frequently takes place in all the inversions of the progression; especially with the third derivative of the diminished seventh. These inversions are set down, Nos. 6—12, inclusive. They hardly require any observation. No. 6, *a*, is very good, notwithstanding the two fifths between the bass and highest part, as the latter is resolved by the opposite motion of these parts; but the bass could not rightly descend to the tonic note, making three fifths in succession, otherwise that motion of the bass might be permitted. But if we resolve the first derivative of the diminished seventh into the second derivative of the dominant, as at *b*, the latter chord may resolve into the common chord of the key. In No. 8, the third inversion of the chord of diminished 7th is resolved by the descent of the bass (the upper parts remaining the same) into the dominant chord. The leap in the bass, from the key-note to the unprepared discord, is not so good as No. 12, which proceeds diatonically.

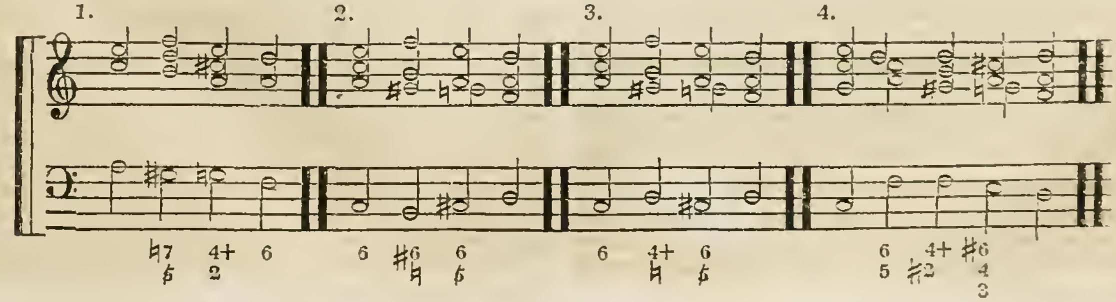
Nos. 13, 14, 15, the diminished seventh, or its inversions, are prepared in the subdominant seventh on the second of the scale, and its inversions. The fifths in No. 13, are good, as shown in what is said No. 6.

158. As the chord of diminished seventh differs from the dominant chord of seventh only by chromatic semitone in the bass, the one very easily passes to the other. Thus the dominant chord of the major principal, by the chromatic rise of the bass, becomes the diminished 7th leading to the relative minor, and furnishes a very agreeable manner of making this transition. Nos. 1—4 show this succession and its derivatives. The reverse of the process brings us back to the principal, Nos. 5—8. And so in general, every dominant may conduct either to its own key, or to its relative minor, or *vice versa*. Thus by means of the dominant which leads to the fifth of the key, we may go to its relative minor, that is, the third of the principal key, No. 9; or from the dominant leading to the 4th of the key, to its relative minor; that is, the second of the principal, No. 10.





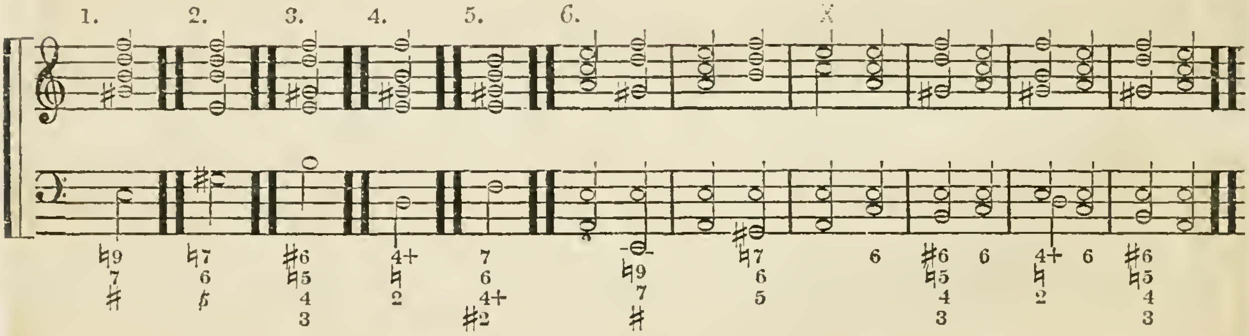
159. Hitherto we have resolved the chord of the diminished seventh on a minor chord, as indeed it belongs properly to the minor mode; yet we shall find this chord very often used to lead to the major mode, or introduced into the modulation of the major mode, without any change of the tonic. In the mean time, we shall exhibit this chord resolving on a new dominant, which is a progression analogous to the sequence of dominants, Arts. 147—149, and, like it, produces a chromatic descent in some of the parts, Nos. 1—4.

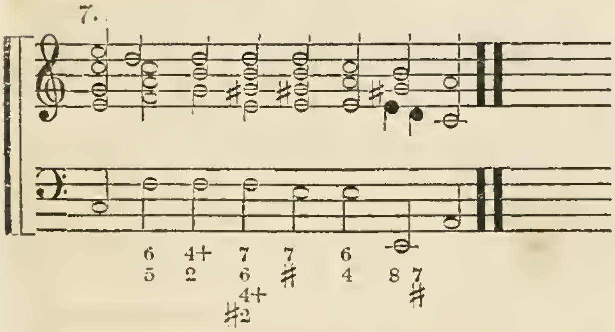


160. The diminished seventh is in truth a minor 9th added to the dominant chord of seventh on the fifth of the key. The whole chord, then, consists of major third, perfect fifth, minor 7th and minor 9th, figured $\begin{smallmatrix}9\\7\\5\\\text{※}\end{smallmatrix}$ with a ♮ or ♭ before the 9, to signify its nature, No. 1. The ninth ought to be kept at the real distance of ninth from the bass, and from that note in all the inversions, because of the harshness of the minor second. It is easy, as we observed of the major 9th added to the dominant chord, to see what addition this will make to all the derivatives of the dominant 7th. To the first inversion it will add a diminished seventh, and the whole will be figured $\begin{smallmatrix}\natural 7\\6\\\text{ƀ}\end{smallmatrix}$ or $\begin{smallmatrix}\flat 7\\6\\\text{ƀ}\end{smallmatrix}$, according to the key, No. 2. To the second inversion of the dominant it adds a lesser fifth, and the nature of both fifth and sixth ought to be signified in the figures thus, $\begin{smallmatrix}\text{※}6\\\natural 5\\4\\3\end{smallmatrix}$, No. 3. To the third inversion of the dominant it will add a minor third, which will be signified by a ♮ or ♭ between the 2 and 4+, thus, $\begin{smallmatrix}6\\4+\\\natural\\2\end{smallmatrix}$, No. 4. Lastly, when the new discord is put in the bass, the dominant chord being in the upper parts, the whole combination will consist of redundant second, greater fourth, major sixth, and major seventh, which will be figured $\begin{smallmatrix}7\\6\\4+\\\text{※}2\end{smallmatrix}$, No. 5. All these chords are struck freely, or with preparation of the discord or discords. The bass of the last chord, No. 5, is generally prepared.

As from the full exhibition we have made of the dominant chord of seventh, and the diminished seventh, the reader can be at no loss to understand the use of this chord, we shall only give M. Choron's general example, No. 6. At the cross X, M. Choron has written A where we have preferred doubling the C, on account of the three fifths in succession. For though these be of different kinds, it is certainly better to resolve the imperfect fifth as we have done. As M. Choron has not exemplified the inversion of the ninth, when that discord is put in the bass, we have added one example of it, No. 7, conducting the modulation from C to A.

But the great use made of this chord in modern compositions, is as the instrument of sudden and distant transitions in the modulation, which it enables the musician to accomplish by means of its *Enharmonic Relations.* This will be the subject of the next chapter.

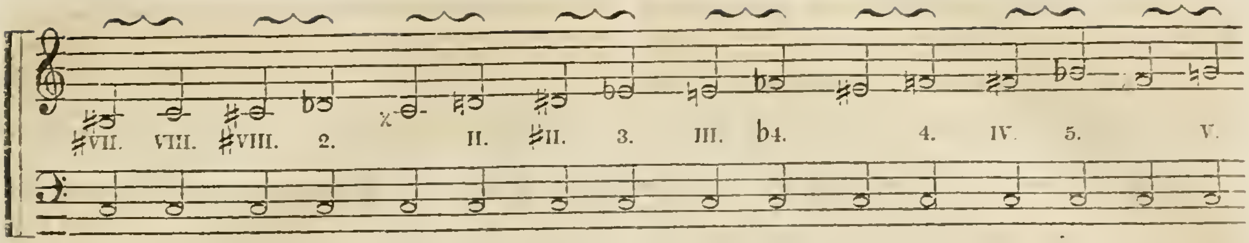


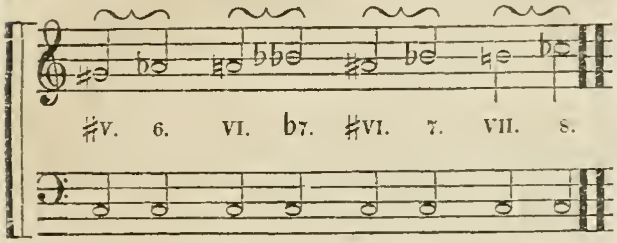


CHAP. VII.

OF THE ENHARMONIC CHANGES IN THE CHORD OF THE DIMINISHED SEVENTH.

161. As the means of conducting the reader to a complete knowledge of this matter, we shall introduce it by exhibiting a Chromatic and Enharmonic scale of twenty-four notes. The upper line is the ascending scale. The pairs united by brackets are the two sounds of the enharmonic diesis, which are both played by the same finger-key on the piano-forte, but which, on perfect instruments, differ by a considerable interval. In the second line, one note, C, is continually repeated; and over each is a figure expressing the exact nature of the interval. Major intervals are figured in the Roman numerals, II, III, IV, &c., and minor intervals by the Arabic figures, 2, 3, 4, &c. A Roman numeral with ※ before it, expresses the redundant intervals, greater than the major by chromatic semitone, as ※II, redundant second, &c. A ♭ before an Arabian figure means the diminished intervals less than the minor of the same name by chromatic semitone, as ♭7, diminished seventh. There are here several intervals which are never used, as CF×; these are not figured. The three first are figured as the real distance; the others as if the bass were an octave higher.

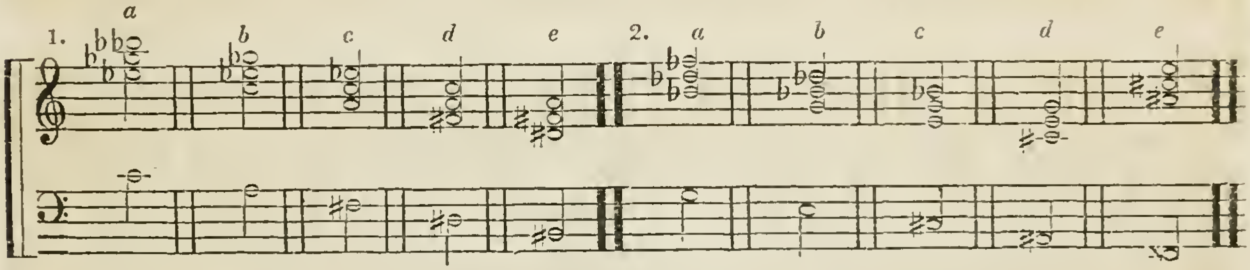


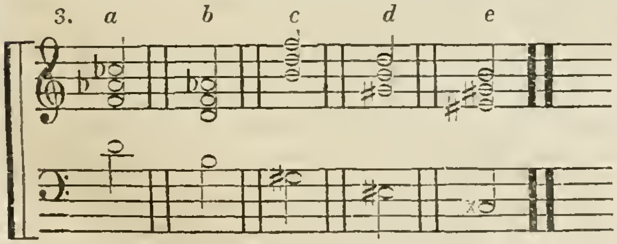


If we should put successively in the bass every other note of the twenty-four, we should find a great many intervals which have never been used, and which have no name. We shall therefore exhibit, in the next page, a Table of all the intervals used in harmony, to every one of the notes of the scale as far as these intervals are furnished. The lowest horizontal line contains the names of the notes, to which those in the perpendicular column are the intervals, as written in the side columns. The lower line of notes is united in pairs by brackets as before, according to the enharmonic relations; and the figures in the perpendicular columns after the same manner.

This Table will be generally useful to young students, who find any difficulty in transposing from one key to another, especially in transposing the chords of the diminished seventh, which some have found perplexing. We must beg the student to banish from his mind, for some time at least, all consideration of the key-board of the piano-forte, and to consider every one of the twenty-four sounds in the above scale as sensibly distinct. For it is from this reference to the key-board, that the confusion and perplexity arise, into which musicians, otherwise respectable, fall in this matter.

162. In a scale of twenty-four notes within the octave, there are fifteen chords of the diminished seventh, which being arranged according to their enharmonic relations, are divided into three sets or series of five each, descending by minor thirds, No. 1, *a*, *b*, *c*, &c. No. 2, *a*, *b*, *c*, &c. No. 3. *a*, *b*, *c*, &c.





163. Now, the chords of diminished seventh of each set, may pass into each other by enharmonic changes, and in consequence carry the modulation into a different key from what was expected. In order to bring under the eye of the student all the transitions that may be made by means of these chords, we put down before the enharmonic changes the two progressions of the diminished seventh already described. In No. 1, the diminished seventh on C, by the chromatic descent of the bass to C♭, becomes the dominant seventh leading to the key of F♭ major; as shown Art. 158, No. 5. Our scale of 24 notes does not furnish a minor third to F♭. In No. 2, the same chord of diminished 7th by the diatonic resolution of the ♭♭7, becomes the first derivative of the dominant chord to the key of D♭ minor or major, as shown in Art. 157, No. 5, *c*. The following progressions, Nos. 3—6, are effected by successive enharmonic changes. In No. 3, B♭♭ is changed enharmonically downwards to A♮, the other parts remaining; and the chord is thus changed into the first derivative of the diminished seventh of A♮, leading to the key of B♭ minor or major. In No. 4, this first derivative of the diminished 7th to A♮, becomes, by the enharmonic changes of the ♭ 5th to the 4+, the second derivative of the chord of diminished 7th to F𝄪, which leads to G minor or major. No. 5 changes this second derivative of the diminished seventh of F𝄪, by the enharmonic descent of the 3d to the 𝄪2, into the third derivative of the diminished 7th on D𝄪, which resolves on the dominant leading to E minor or major. Lastly, in No. 6 this third derivative of the diminished seventh to D𝄪, by the enharmonic descent of the bass to B𝄪, becomes the chord of diminished 7th to that note, which resolves on the dominant leading to C𝄪 major or minor.

Now when we examine this series of key-notes to which our chord has conducted us, we find them descending in minor thirds thus, F♭, D♭, B♭, G, E, C𝄪; and these are the notes belonging to our second set of chords of diminished

Table of all the Intervals used in Harmony to every Note of the Scale of Twenty-four Notes in the Octave, as far as the Intervals are furnished.

※VIII		c※	c×	d		d※		e	e※	f		f※	f×	g		g※		a	a※	b♭		b	b※	c	※VIII
VIII	b※	c	c※	d♭	c×	d	d※	e♭	e	f♭	e※	f	f※	g♭	f×	g	g※	a♭	a	b♭♭	a※	b♭	b	c♭	VIII
8	B	C♭	C		C※	D♭	D		E♭		E	F♭	F		F※	G♭	G		A♭		A	B♭♭	B♭		8
VII		B	B※	C		C※	C×	D	D※	E♭		E	E※	F		F※	F×	G	G※	A♭		A	A※	B♭	VII
7	A※	B♭	B	C♭	B※	C	C※	D♭	D		D※	E♭	E	F♭	E※	F	F※	G♭	G		G※	A♭	A	B♭♭	7
※VI		A※		B		B※		C※	C×	D		D※		E		E※		F※	F×	G		G※		A	※VI
♭7	A	B♭♭	B♭		B	C♭	C		D♭		D		E♭		E	F♭	F		G♭		G		A♭		♭7
VI		A	A※	B♭		B	B※	C	C※	D♭	C×	D	D※	E♭		E	E※	F	F※	G♭	F×	G	G※	A♭	VI
6	G※	A♭	A	B♭♭	A※	B♭	B	C♭	C		C※	D♭	D		D※	E♭	E	F♭	F		F※	G♭	G		6
※V		G※		A		A※		B	B※	C		C※	C×	D		D※		E	E※	F		F※	F×	G	※V
V	F×	G	G※	A♭		A	A※	B♭	B	C♭	B※	C	C※	D♭	C×	D	D※	E♭	E	F♭	E※	F	F※	G♭	V
5	F※	G♭	G		F※	A♭	A	B♭♭	B♭		B	C♭	C		C※	D♭	D		E♭		E	F♭	F		5
IV		F※	F×	G		G※		C	A※	B♭		B	B※	C		C※	C×	D	D※	E♭		E	E※	F	IV
4	E※	F	F※	G♭	F×	G	G※	A♭	A	B♭♭	A※	B♭	B	C♭	B※	C	C※	D♭	D		D※	E♭	E	F♭	4
III		E	E※	F		F※	F×	G	G※	A♭		A	A※	B♭		B	B※	C	C※	D♭	C×	D	D※	E♭	III
3	D※	E♭	E	F♭	E※	F	F※	G♭	G		G※	A♭	A	B♭♭	A※	B♭	B	C♭	C		C※	D♭	D		3
※II		D※		E		E※		F※	F×	G		G※		A		A※		B	B※	C		C※	C×	D	※II
♭3	D		E♭		E	F♭	F		G♭		G		A♭		A	B♭♭	B♭		C♭		C		D♭		♭3
II	C×	D	D※	E♭		E	E※	F	F※	G♭	F×	G	G※	A♭		A	A※	B♭	B	C♭	B※	C	C※	D♭	II
2	C※	D♭	D		D※	E♭	E	F♭	F		F※	G♭	G		G※	A♭	A	B♭♭	B♭		B	C♭	C		2
	B※	C	C※	D♭	C×	D	D※	E♭	E	F♭	E※	F	F※	G♭	F×	G	G※	A♭	A	B♭♭	A※	B♭	B	C♭	

seventh. There are two remaining sounds of that set, viz. A※ and F×: but to these we cannot make a modulation, as our scale of 24 sounds does not furnish their leading notes, which would be G× and E×.

Of these six keys, the 1st and 5th, *i. e.* F♭ and E♮, as also the 2d and 6th, D♭, and C※, are played by the same finger-keys on the piano-forte. But it is not on that account less important to distinguish them. In very distant modulations, it may be of no great consequence which we should take. As, for instance, from the principal key of C, it is a matter of little consequence whether we go to C※ or D♭; but in many cases it is essential to make the distinction. Thus, from the principal key of A♭ major, or of F minor, we must go to D♭, and not to C※, which is no way related to the primary key. From the key of A or of E major, again we must go to C※, and not to D♭.

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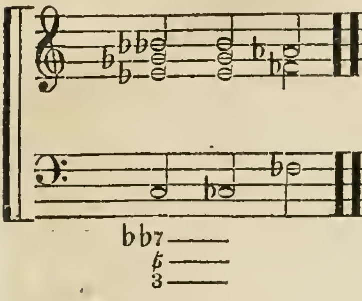

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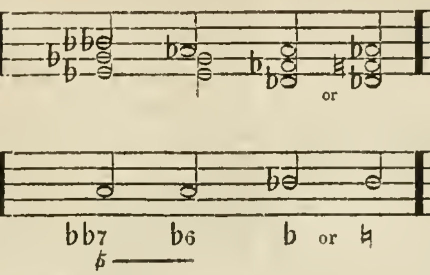

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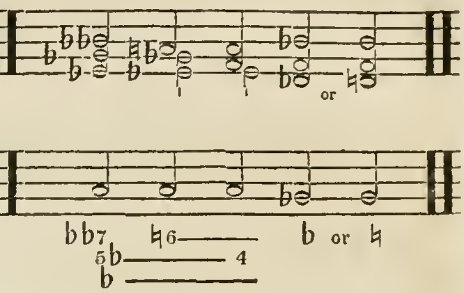

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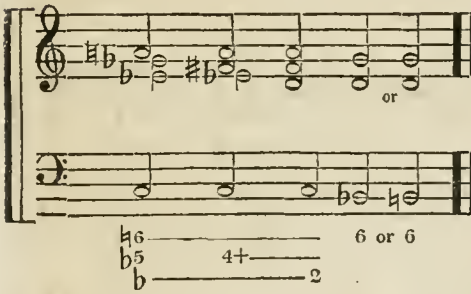

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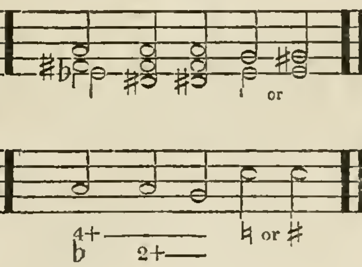

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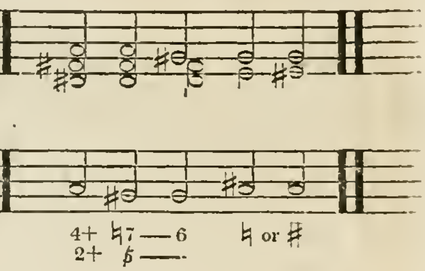
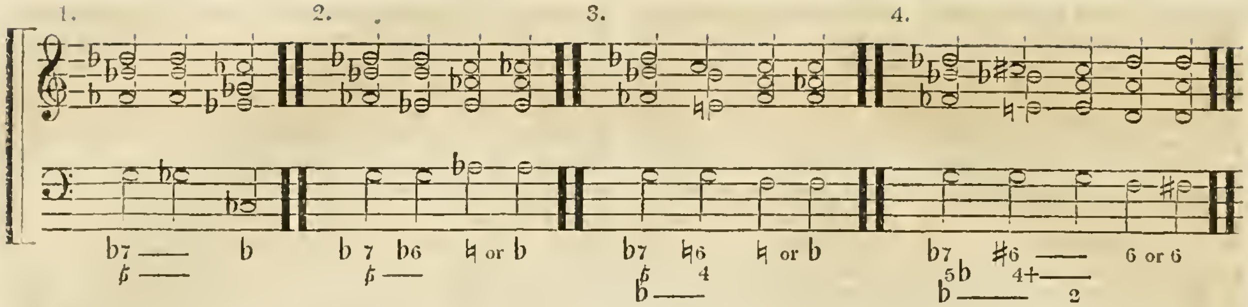
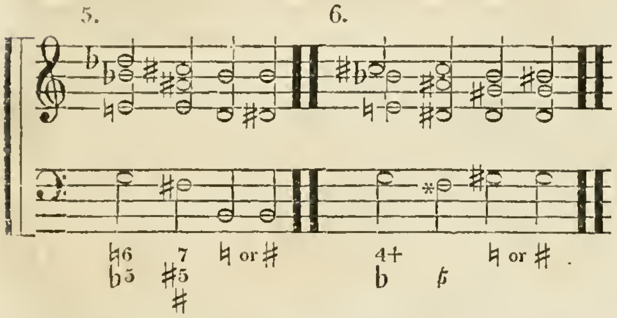


164. The enharmonic change of one part of the chord, as in these examples, has a very agreeable effect when performed on instruments capable of making the change real. Two or more parts, and even the whole chord, may be changed all at once; at least, we shall often meet with such in the compositions of the best musicians. The effect, however, becomes less and less pleasing, according to the number of parts changed. The change of the whole chord, in our judgment, has not a good effect. We are able to speak of these changes, from having had an opportunity of hearing them on an instrument which gave them with the most perfect truth; but we shall recur to this subject when we come to treat of a system of perfect intonation.

In the mean time, we observe, that it can very seldom be necessary to change more than two parts of the chord enharmonically; and this may be done successively, or at once. Of the successive changes, the examples in the last article are sufficient. In these also, the enharmonic change is first made, and then the resolution into the dominant chord leading to the new key; but the enharmonic change and resolution into the dominant chord, may take place at the same time. These we shall exhibit in the second set of chords of diminished seventh, Nos. 1—6. The two first examples are set down, as in the preceding article, for the sake of showing all the keys to which this set of chords conduct the modulation. In No. 3, the diminished 7th to G is changed enharmonically to the major sixth; and at the same time the ƀth resolves diatonically on the perfect fourth, so that the chord has become the second inversion of the dominant leading to F major or minor. These changes at No. 3, in the preceding article, are made successively. In No. 4, the chord of diminished seventh by the enharmonic changes of the b7th and ƀth, becomes the second inversion of the chord of diminished 7th on C※, and then this is resolved into the third inversion of the dominant of the key of D major or minor. The resolution might take place at the same time with the enharmonic changes, which is only omitting the second chord, and playing the third at once in its stead, and then the changes effected in Art. 163, Nos. 2 and 3, by three successive steps, would be effected at once. In No. 5, the first inversion of the diminished seventh, by the enharmonic changes of the ♭5 and minor third, and at the same time by the diatonic resolution of the bass, becomes the dominant chord of seventh leading to B major or minor; thus effecting at once what in Art. 163, Nos. 4 and 5, is brought about by three successive steps. In No. 6, the second inversion of the chord of diminished seventh by the enharmonic changes of the 3d and of the bass, and at the same time by the diatonic resolution of the 6th, becomes the first derivative of the dominant leading to G※ major or minor; the whole changes which in Nos. 5 and 6, Art. 163, are brought about by three successive steps, being accomplished at once.

The keys, then, to which this second set of chords of diminished seventh, lead the modulation, are C♭, A♭, F, D, B, and G※, descending by minor thirds, being all the sounds in the third set of diminished sevenths except E※ and C×, to which we have no leading note.

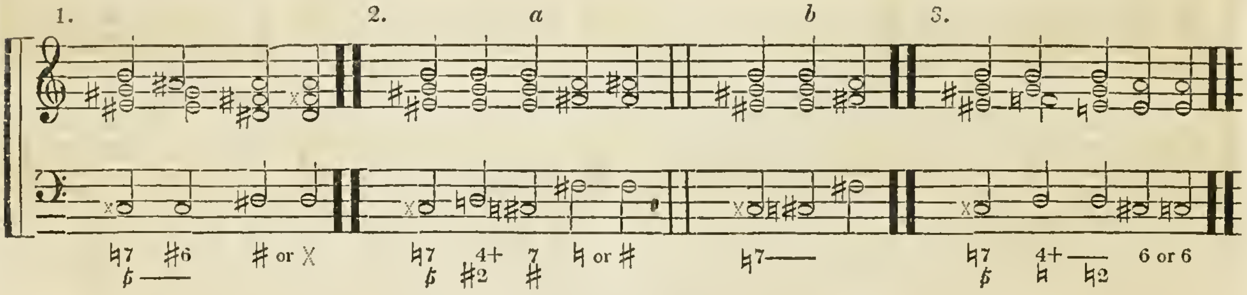


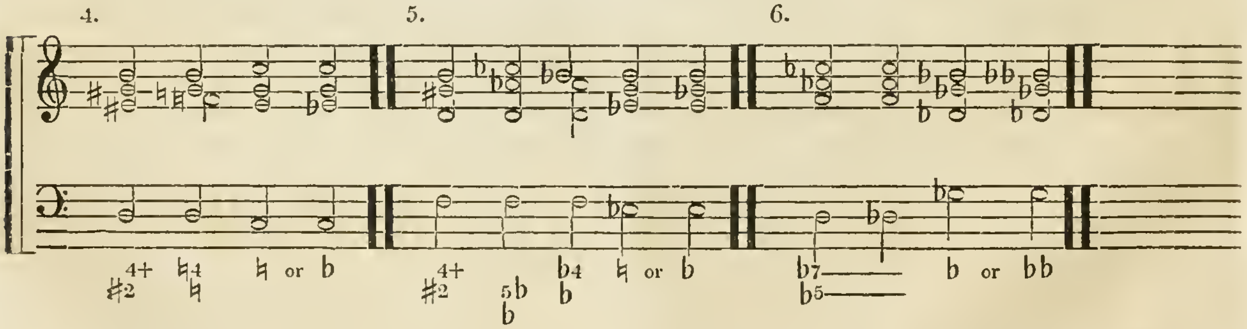


165. Hitherto we have shown only one kind of enharmonic change, namely, downwards. But the changes may be made in the opposite direction, reversing the former process. These we shall exhibit in the third set of diminished sevenths, beginning therefore with the lowest.

No. 1 shows the chord of diminished 7th on C ×, resolving diatonically on the dominant of D※, the key to which it belongs. No. 2, *a*, shows the same chord of diminished 7th, by the enharmonic change of the bass upwards to D ♮, becoming the third inversion of the chord of diminished 7th on E※, which resolves diatonically on the dominant leading to F※ minor or major. At *b*, the second chord is omitted, and then we have the chromatic descent of C × to C※, carrying dominant chord of 7th to the same key. In No. 3, the same chord of diminished seventh by enharmonic changes upwards of the bass and third, becomes the second inversion of the diminished 7th to G※, which resolves diatonically on the dominant leading to A major or minor. If the second chord were omitted, the passage to the dominant of A would be by the enharmonic change upwards of the bass, and the chromatic descent of the third E※ to E♮. What is equivalent to this, is done in No. 4, where the third inversion of the diminished seventh to E※ becomes, by the enharmonic change of the redundant second to minor third, and the chromatic descent of the major fourth to perfect fourth, the second derivative of the dominant of the key of C major or minor. After the same manner, in No. 5, we come to E♭ major or minor; and in No. 6, to G♭ major or minor.

Now these keys are an ascending series of minor thirds, D※, F※, A, C, E♭, G♭, being the notes of the first set of chords of diminished seventh, except B※ and B♭♭.

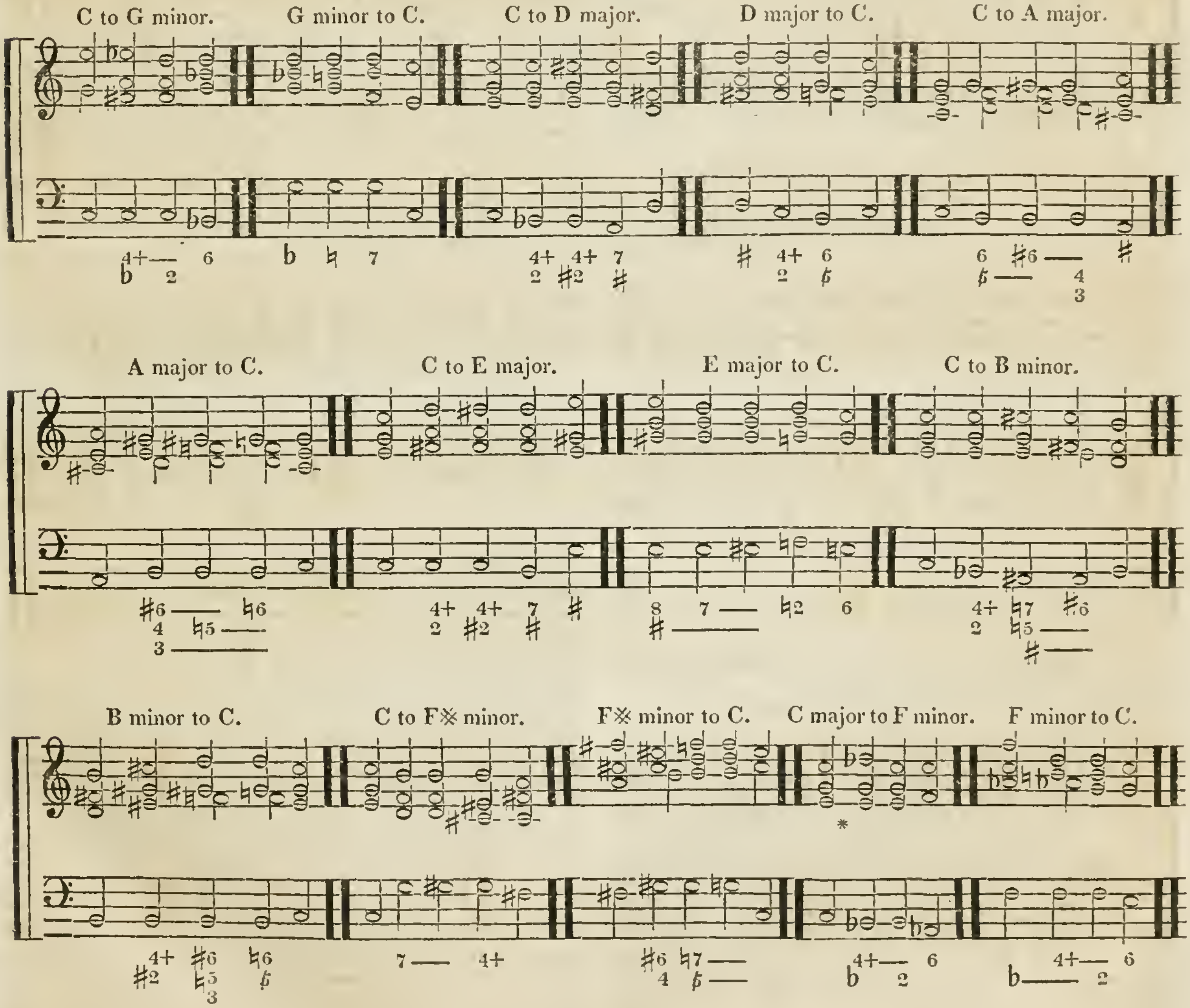




The reader sees how much these enharmonic changes put it in the power of the composer to effect very sudden and distant transitions in the modulation. Hence it is that the chord of diminished seventh has been called the *equivocal chord*, an appellation to which it is very well entitled.

166. The keys to which these three sets of chords conduct, amount to eighteen out of the twenty-four. It is plain that there remains but one question to be solved, in order to our being able to make a transition from any key to any other, however little related to it; namely, how we may get to

any one of these sets of chords. This is no difficult matter. We have shown, Art. 158, how easily we go from a dominant chord to a chord of the diminished seventh; and this, by the transformations already explained, takes us easily to any one of the six keys of that series. Now, in every case, the dominant to the fifth of the key belongs to one of the two remaining sets; and the dominant of the fourth of the key, to the other. It is thus the simplest matter imaginable to get to a chord of the diminished seventh, which will either immediately, or by enharmonic changes, bring to the key we would go to. The following examples contain transitions from C major to eleven keys, becoming more and more distant; and the return from each to C. The reader will observe, that when the modulation has proceeded from the dominant leading to the fifth of the principal, the return is made by means of the dominant leading to the fourth of the key from which we are to return. Thus we go to E through the dominant conducting to G, and we return through the dominant of A. When again the modulation goes from the dominant leading to the fourth of the principal key, we return through the dominant leading to the fifth of the key whence we are returning; and when we go by means of the dominant of the principal, we return through the dominant of key whence we are returning. In this last case, the chords may be the same by which we came, taken in reverse order. For example, going and returning to and from A, as also to and from E♭, the chords are the very same even in position. In performing these examples, each chord ought to be repeated several times, by which means the effect will be brought out. Thus the first example may be performed as at A, terminating with a formal close, which completely establishes the new key. With these remarks we leave these transitions to the consideration of the student.



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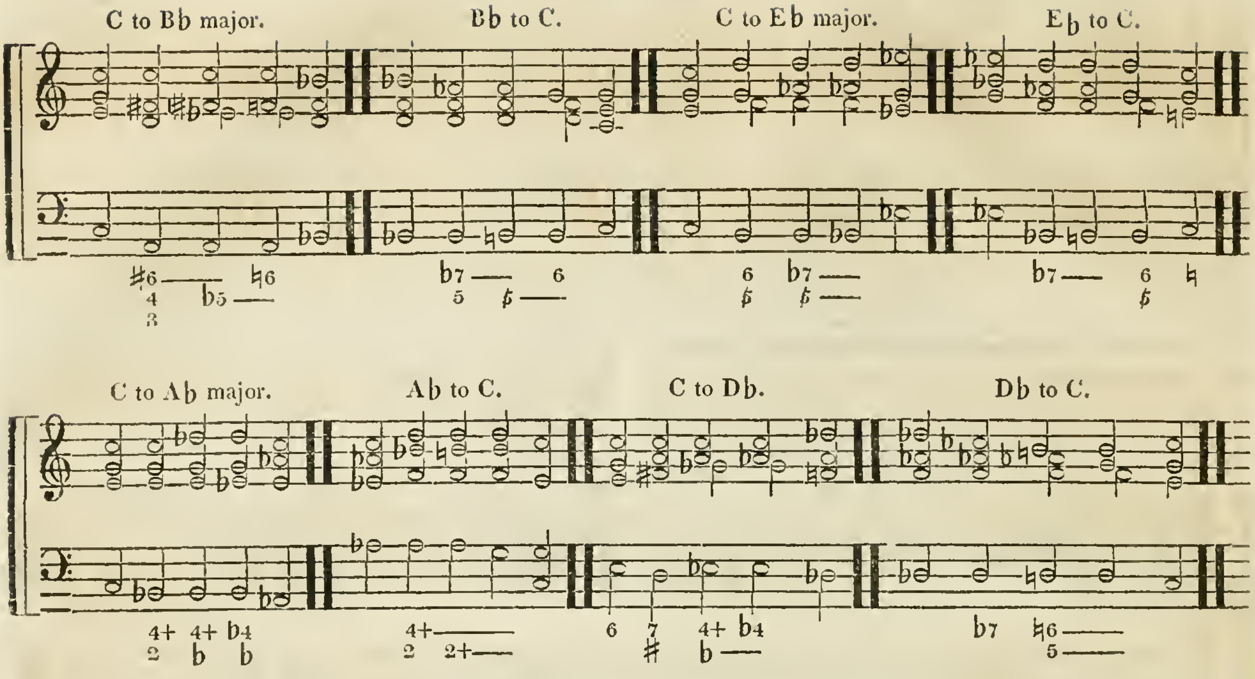
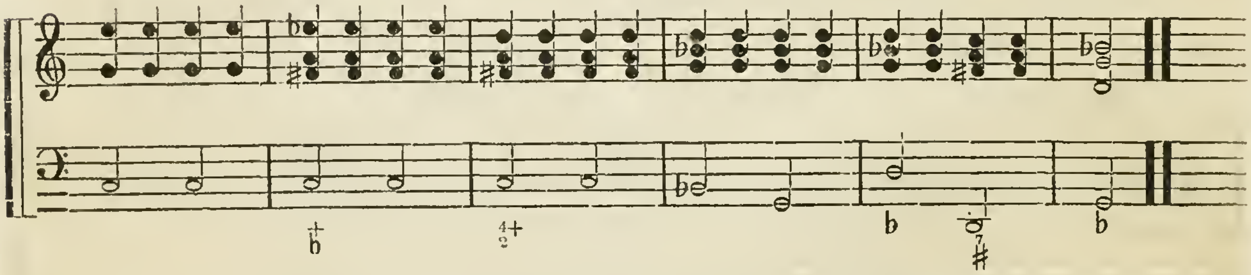
* The D♭ in the highest part here feels harsh, like a false relation to the C♮ in the bass of the first chord. It is better introduced in the examples modulating from C to B, and from C to A♭



A. *Showing the manner of performing the above Modulations.*



CHAP. VIII.

OF THE RESOLUTION OF THE SEVENTH, THE FUNDAMENTAL BASS DESCENDING BY THIRD.

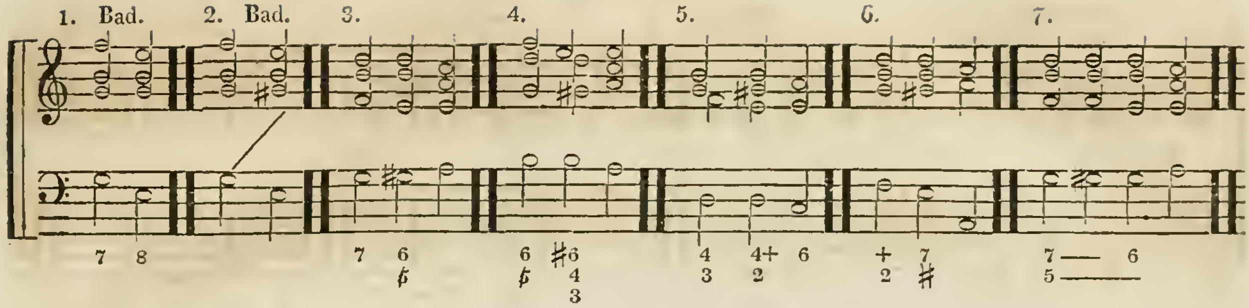
OF OTHER CHORDS NOT HITHERTO NOTICED.

167. Besides the two resolutions of chords of the seventh, which we have already noticed, viz. as in the greater cadence, the bass descending fifth, and as in the broken cadence, the bass ascending one degree of the diatonic scale, there is yet a third, viz. into a chord, the bass of which is third below, or sixth above the fundamental bass of the chord of seventh. This, however, is not practised with the fundamental chord of seventh, for a reason which will immediately be seen; but several of the derived successions are very good.

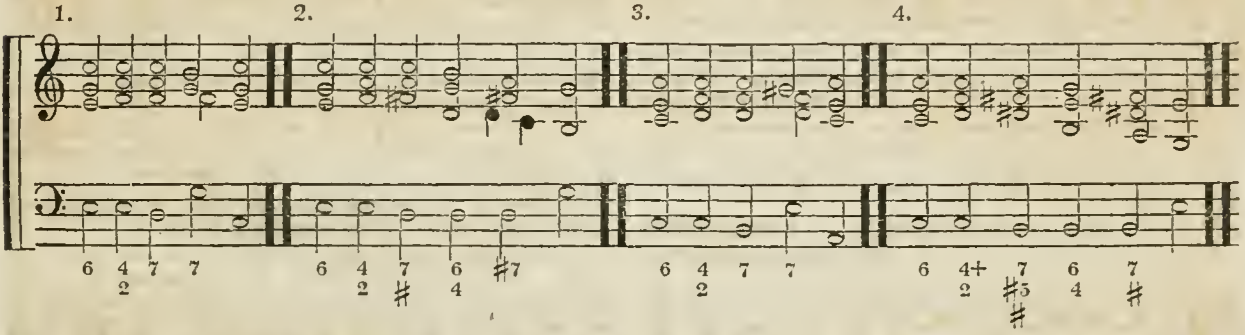
If the discord, that is, the seventh, resolve by diatonic semitone, and the sensible note, instead of resolving upwards, remain stationary, and if the bass at the same time descend by minor third, or rise major sixth, we shall have a minor common chord, No. 1. But the descent of bass by third is bad, because of the resolution of the 7th on the octave, which feels like octaves, as before observed; and the leap by sixth, in contrary motion, is no better. If, at the same time, the octave in the first chord rise chromatically, as in No. 2, there is, besides the former fault, the additional harshness of false relation of octave crossways. Yet this last succession gives several very good derived ones.

Rameau called this progression the interrupted cadence; and even M. Choron, who affects to despise Rameau, calls it so;—but certainly with no great propriety; for though the derivative successions be good in a stream of harmony, yet the want of the resolution of the imperfect fifth makes it so little satisfactory, that it is not very fit to terminate a harmonical phrase. "Of this progression at a rhythmic close," says Dr. Callcott, "there are few, if any, practical examples." We shall, however, afterwards take an opportunity of quoting from the best masters, instances, in which both the direct chord and its derivatives are used in cadences to terminate musical phrases. Here they would be out of place.

The chord on which this resolution takes place, is generally another dominant, direct or inverted. Thus Nos. 3—6 are examples of such progressions carrying to the relative minor. The reader will easily see, that this progression does the same in effect as the diminished seventh, succeeding the dominant by the chromatic ascent of the bass. Thus, No. 3 is the same progression with No. 7; only omitting the second chord, which is the diminished seventh.



168. In other sevenths, a similar resolution, at least of the third derivative, is practised. Thus the $\begin{smallmatrix}4\\2\end{smallmatrix}$, third derivative of the major seventh, resolves on the subdominant chord of seventh on the second of the scale, as in No. 1. Or it may resolve on the dominant chord leading to the fifth of the key, as in No. 2. So after the same manner in the minor mode, as in Nos. 3 and 4.



169. In the table of intervals, given in Art. 161, there is one called the *diminished third*, being chromatic semitone less than the minor third. It is equal to two diatonic semitones. Thus, supposing the scale truly tuned, E♭ minor third to C, D diatonic semitone below E♭, and C※ diatonic semitone below D, the interval D※ E♭ is plainly equal to two diatonic semitones, and chromatic semitone less than the minor third CE♭.

On keyed instruments this interval is confounded with the major second, from which it differs by the enharmonic diesis, being so much sharper. By inversion it becomes a redundant sixth, being enharmonic diesis flatter than the minor seventh, which is played by the same finger keys.

There is a wonderful difference in the effect of these intervals, which are confounded on keyed instruments. Both the major second and minor seventh are decidedly dissonant. But the effect of the diminished third and redundant sixth, is so rich and agreeable to the ear, that they seem hardly to require resolution, insomuch that we are at a loss almost to say whether we should call these intervals discords, or a peculiar kind of concords. Yet the rules which are laid down for the use of their intervals, proceed on the extreme harshness of the diminished third; a character which we can assure our readers does not belong to it. This mistaken notion has arisen from musicians not having had any opportunity of hearing these intervals truly tuned. For though the violin tribe of instruments be capable of producing every interval perfect, performers never having heard the intervals in question, have not made the distinction, or at least the accurate comparison which we have had frequent opportunities of making on an instrument which gave all intervals with perfect truth. But though we have made these remarks, we shall give the usual rules for the treatment of these intervals, leaving it to future legislators to abrogate such as they may deem unnecessary.

170. The imperfect fifth contains the intervals of major third and diminished third. We may thus have two chords of the imperfect fifth different from that which we have hitherto seen, according as we put the major third or diminished third next the bass.

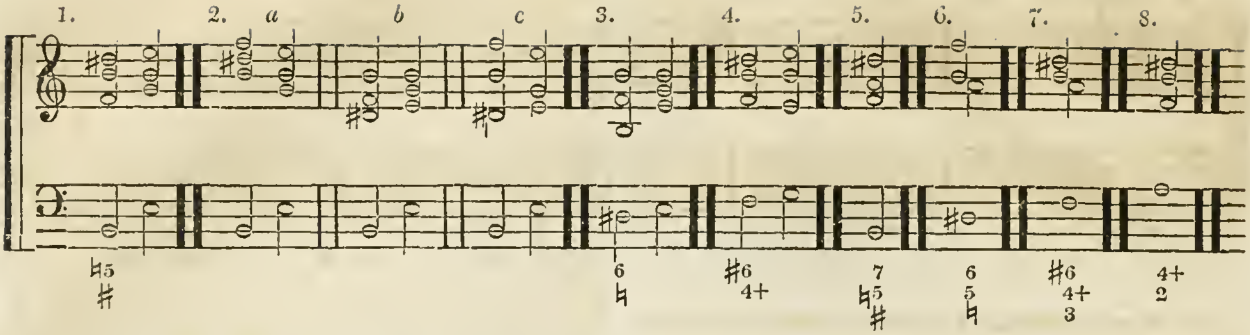
The former of these chords belongs exclusively to the second of the minor scale, the third of the chord, (fourth of the scale) being raised chromatic semitone in passing to the chord of the fifth of the key, No. 1. Mr. Kollmann, from whom this example is taken, says "that the chord is good in this position, yet it would be bad in the positions, No. 2, *a*, *b*, because they contain the *disagreeable* combination of a diminished third from D※ to F, besides the imperfection of the harmony itself. Yet at the distance of a tenth, and covered with a middle part, which stands in good relation with the higher as well as lower notes, such as at *c*, even that diminished third may be used." The same observations are to be made with regard to the inversions of the chord, as Nos. 3 and 4.

To this chord the minor seventh is added; and in this form Monsieur Choron calls it the diminished chord of the tonic dominant. By the word *diminished*, is meant the lesser or imperfect fifth, an improper application of the word, which many excellent writers have used, especially in Germany. This chord, then, consists of major third, imperfect fifth, and minor 7th, figured $\begin{smallmatrix}7\\ \natural 5\\ \text{※}\end{smallmatrix}$. The distance from the third to the fifth must be at least the redundant sixth, No. 5.

The first derivative consists of diminished third, minor fifth, and minor sixth, and is figured $\begin{smallmatrix}6\\ 5\\ \natural\end{smallmatrix}$. The third ought to be at the distance of tenth at least, No. 6.

The second derivative consists of major third, major fourth, and redundant or *superfluous* sixth, for these two words are used as synonymous, figured $\begin{smallmatrix}\text{※}6\\ 4+\\ 3\end{smallmatrix}$, No. 7.

The third derivative consists of major second, major fourth, and minor sixth, figured $\begin{smallmatrix}\natural 6\\ 4+\\ 2\end{smallmatrix}$, No. 8.



171. We shall copy M. Choron's examples and remarks on the use of this chord.

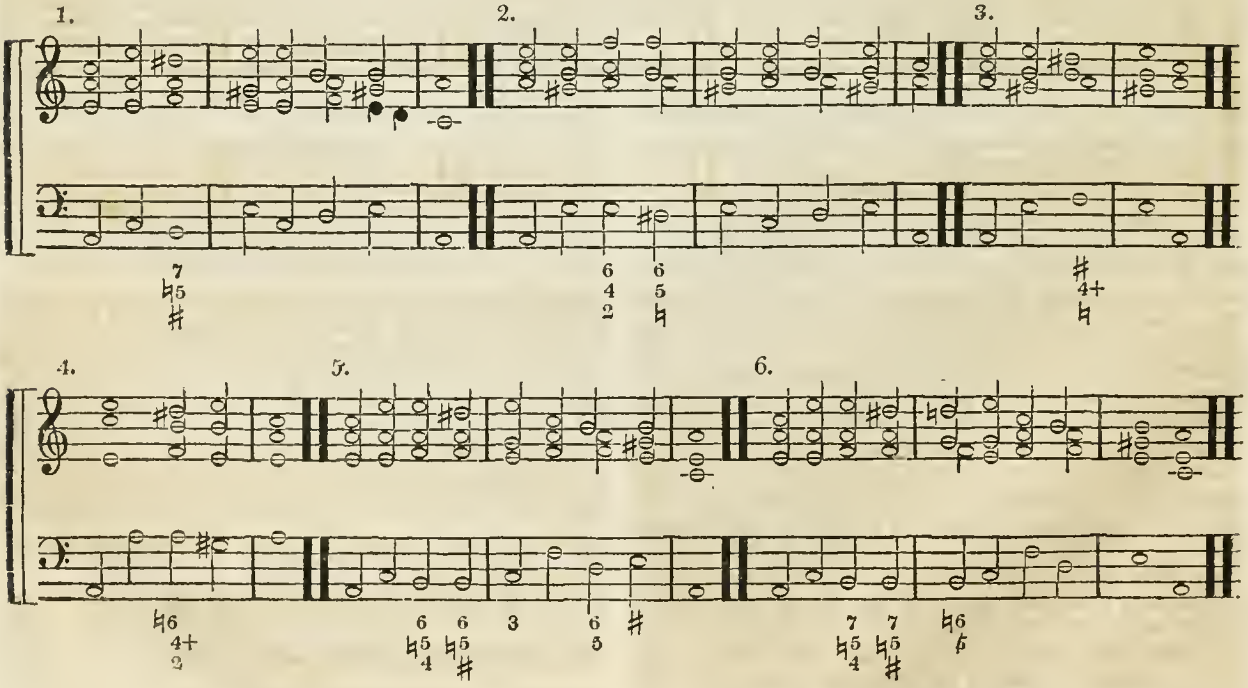
"This chord, which belongs to the second note of the minor key, become dominant with regard to the fifth, has all the characters and properties of a tonic dominant chord," (*i. e.* which closes on the tonic.) "It may, like it, be used without preparation, having respect nevertheless to the laws of modulation. It has, like that chord, the three resolutions of fourth and second ascending, and of third descending. It also may proceed by descending a second. We shall examine these different resolutions, confining ourselves to the most ordinary cases.

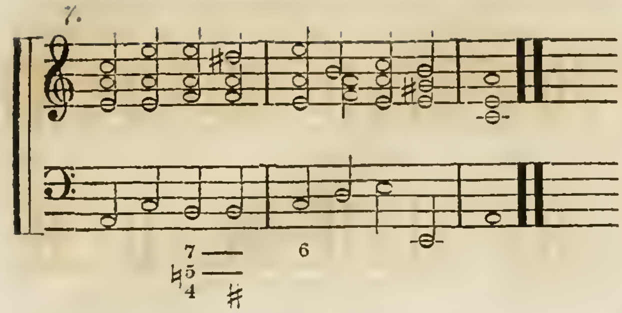
"1st. Procedure by fourth ascending, or perfect cadence. —*Direct or fundamental chord.* This harmony, that it may be characterized, must be used in four parts; for if we suppress the fifth, we cannot know exactly the nature of the chord, as the fifth might be either perfect or minor. We must recollect, that the major third and minor fifth, which form diminished third, must be at the distance of superfluous sixth, No. 1.—*First derivative.* This chord can hardly be used without preparation, because of the diminished third, which is very harsh without that precaution, No. 2.—*Second derivative.* This chord is employed without any kind of preparation. It is very much used. We shall observe, however, that the superfluous sixth is better by suppressing the fundamental note, which is here the fourth to the bass, No. 3. —*Third derivative.* This chord is used without preparation, though it is prepared in this example. The major fourth and lesser sixth, which form diminished third, must be at the distance of redundant sixth, No. 4.

"2d. Procedure by second ascending, or broken cadence. This procedure, which has never been examined in any didactic work, is nevertheless of very fine effect. We shall only examine the fundamental procedure, the others being hardly susceptible of being employed, No. 5.

"3d. Procedure by third descending, or interrupted cadence. This procedure, which, like the former, has never been examined, is also of very fine effect, at least in one of its derivatives; that is to say, in the passage of the first chord fundamental to the first derivative of the second chord, No. 6.

"4th. Procedure by descending second. This procedure, not hitherto observed, produces also a succession of very good effect, as may be seen in the example, No. 7."



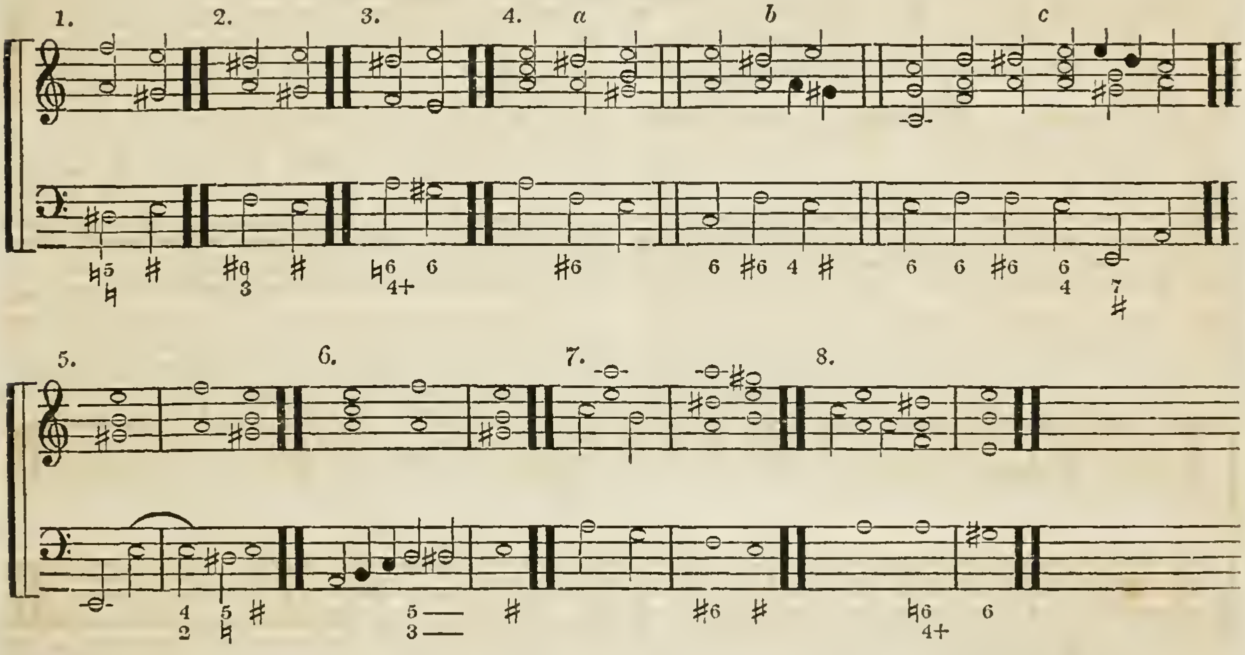


172. If we accompany the imperfect fifth with the diminished third, we must, according to the rules above observed, keep the third at the distance of tenth from the bass. It belongs to the fourth of the scale, minor mode, accidentally sharpened in passing to the fifth of key. It is figured $\begin{smallmatrix}\not 5\\ \natural\end{smallmatrix}$ or $\begin{smallmatrix}\not 5\\ \flat\end{smallmatrix}$, according to the signature at the clef, No. 1.

The first inversion consists of major third and redundant or superfluous sixth, figured $\begin{smallmatrix}\times 6\\ 3\end{smallmatrix}$, or $\begin{smallmatrix}\natural 6\\ 3\end{smallmatrix}$, if there be many flats at the clef, No. 2.

The second inversion consists of major fourth and minor sixth, figured $\begin{smallmatrix}\natural 6\\ 4+\end{smallmatrix}$, or $\begin{smallmatrix}\flat 6\\ 4+\end{smallmatrix}$, according to the number of flats at the clef. The distance between the 4+ and ♮6th, ought to be not less than redundant sixth.

Of these three chords, the first derivative, No. 2, which Dr. Callcott calls the Italian sixth, is by much the most in use. It may be struck freely immediately after the minor tonic, as No. 4, *a*, or after its first inversion, as at *b*, which is better, as avoiding the cross relation of greater fourth between the bass of the first chord and the redundant sixth. The resolution into the leading chord of the key, is often retarded by the $\begin{smallmatrix}6\\ 4\end{smallmatrix}$, as at *b*. This chord leads very agreeably from the major key to the relative minor, by the subdominant sixth, rising chromatically to the redundant sixth, as at *c*. But this goes still better in four parts, when the redundant sixth is accompanied with major third and perfect fifth, as we shall see bye and bye.



The direct chord, and the second inversion, do not admit of so free an employment. We shall give M. Choron's examples and observations, Nos. 5—8 inclusive.

"This chord, as we have already observed, belongs exclusively to the fourth of the minor scale, chromatically sharpened, and rising to the fifth. This chord is truly appellative," (that is, calls for or raises the expectation of the succeeding harmony): "the fundamental note and its third must pass to the fifth of the key; the lesser fifth ought to descend on the third of the following chord. In four parts this note may be doubled, and rise to the fifth; but this in one of the middle parts, and in the first or second derivative. It ought to be remarked, also, that the fundamental chord is hardly employed without preparation, on account of the diminished third, which is very harsh of itself. This preparation consists in retarding the fundamental note, No. 5; or in employing it by chromatic alteration as a passing note, by striking first the other sounds of the chord, No. 6."

173. To this chord of imperfect fifth and diminished third, the diminished seventh is added, which is figured $\begin{smallmatrix}\natural 7\\ \not 5\\ \natural\end{smallmatrix}$, or $\begin{smallmatrix}\flat 7\\ \not 5\\ \flat\end{smallmatrix}$, No. 1, according to the signature at the clef. It is unnecessary to repeat the rule about the interval of diminished third. The first derivative consists of major third, perfect fifth, and redundant sixth, figured $\begin{smallmatrix}\times 6\\ 5\end{smallmatrix}$. Dr. Callcott calls this the German sixth, No. 2.

The second derivative consists of minor third, major fourth, and minor sixth, figured $\begin{smallmatrix}\natural 6\\ \times 4\\ 3\end{smallmatrix}$, No. 3.

The third inversion consists of redundant second, perfect fourth, and major sixth, No. 4.

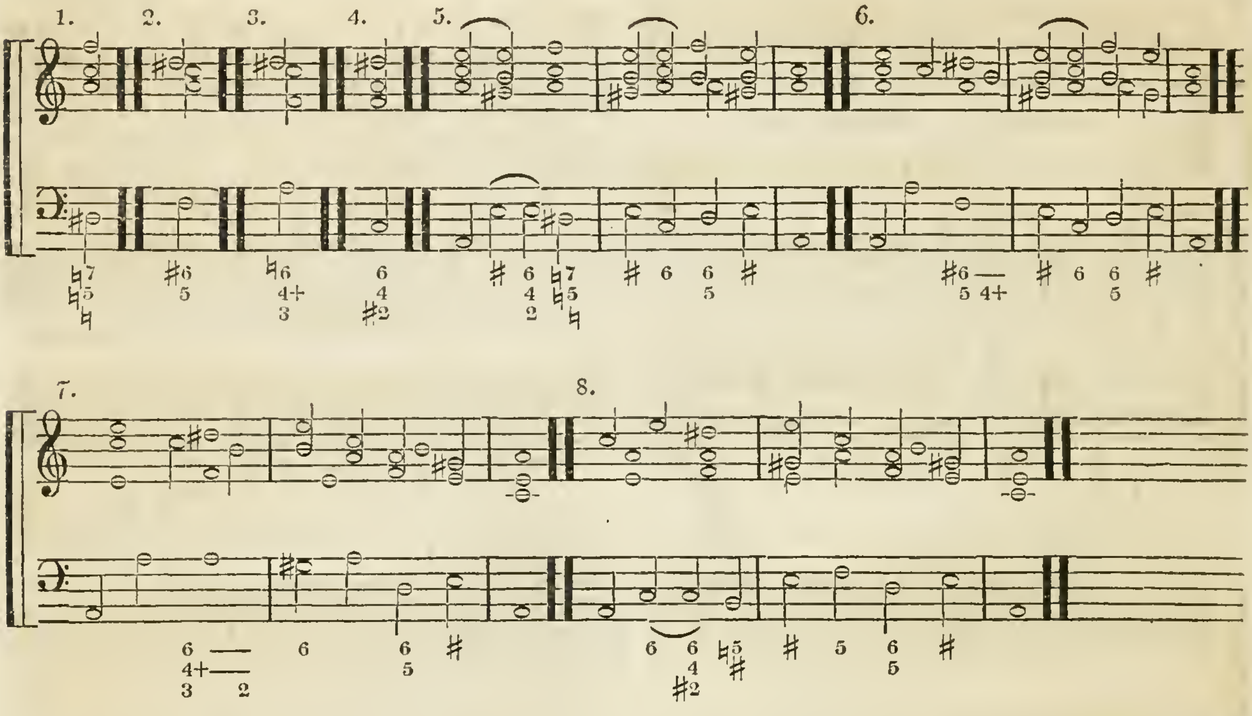
For the employment of these chords, we shall begin with M. Choron's examples and rules; and then subjoin some observations on the first derivative, which is the most important, and most practised.

" *Direct chord.* We have already seen, that this chord can hardly be employed without preparation, on account of the diminished third, and we have explained what kind of preparation is suitable. We retrace here the example, (with the addition of diminished 7th,) No. 5.

" *First derivative.* This chord, which is the best, is used without preparation; but the note, which is fifth to the bass, must, previously to the resolution of the other parts, descend on the major fourth to the bass, in order to avoid the two fifths. By this movement we pass into the chord of dominant with imperfect fifth, (described Art. 170, 171,) No. 6.

" *Second derivative.* This derivative is employed without preparation. The major fourth and minor sixth must be at the distance of superfluous sixth; the third ought to descend one degree before the resolution, in order to avoid the two fifths between the parts, No. 7.

" *Third derivative.* This chord is employed without preparation. We must avoid the interval of diminished third, as in the preceding examples," No. 8.

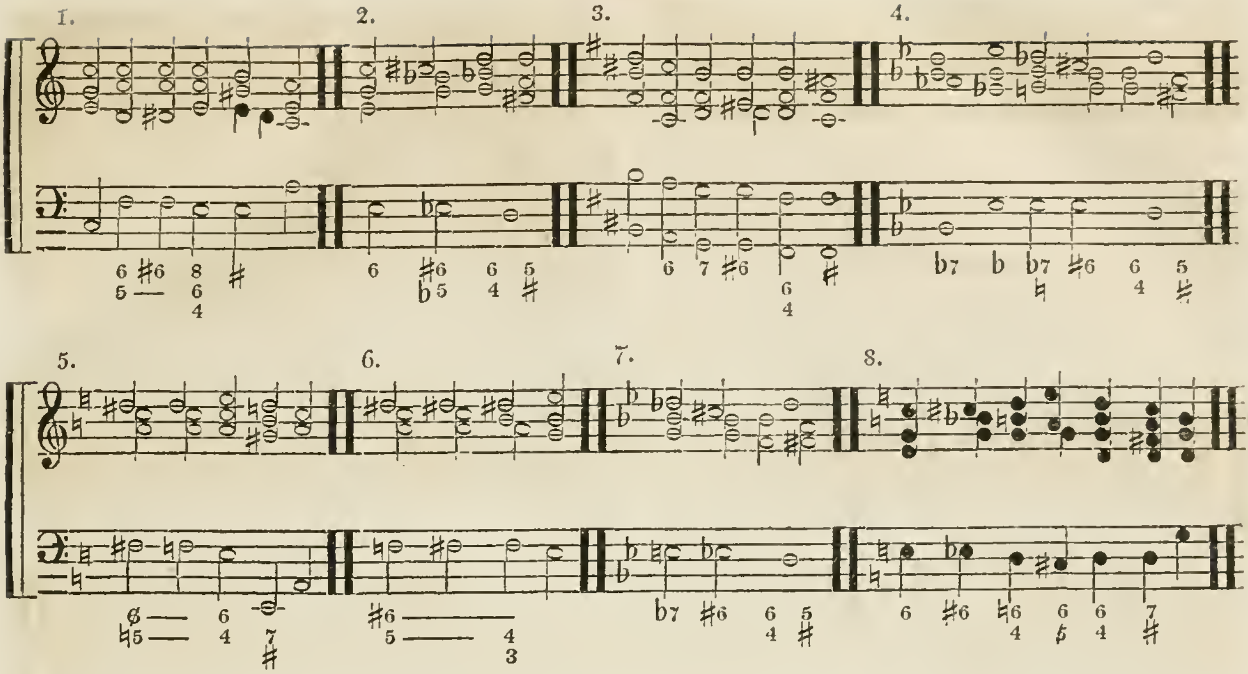


174. M. Choron, in the last article, No. 6, in order to avoid consecutive fifths, makes the fifth accompanying the redundant sixth, descend on the greater fourth. But this is not the most usual manner of treating the chord. It is first resolved on the fourth and sixth by the parts, which form redundant sixth, moving from each other to the octave, while the other parts remain, and then resolve into third and fifth, as in No. 1. In this example it follows the subdominant $^{6}_{5}$ by chromatic rise of the sixth. It may follow the chord of lesser sixth by the chromatic movement of the parts in opposite directions, as in No. 2. It frequently follows the chord of major seventh on the same bass, as in No. 3, which is taken from a *sanctus* of Graun, as quoted by Mr. Shield: and this is the conclusion of a strain. Hadyn also concludes the first strain of a symphony by this resolution of the redundant sixth on the dominant major common chord: the passage we may quote in a subsequent part of our work.

As the chord of redundant sixth only differs from the dominant chord of minor seventh by the enharmonic difference between the sixth and seventh, the latter easily passes into the former by enharmonic change. No. 4 is taken from Callcott's Grammar, where it is quoted from a chorus of Handel. This enharmonic change has a delightful effect when all the intervals are taken quite true. This change, as M. Choron justly observes, may be practised on all dominants, however related to the principal key, and thus we may open new routes of modulation. The redundant sixth resolves on a dominant third, leading to a key diatonic semitone below that of the dominant, from which it is thus taken.

It differs also from the first derivative of the diminished seventh, by chromatic semitone in the bass, and these two chords may easily pass into each other, Nos. 5 and 6. Haydn has changed the direct chord of diminished seventh, by chromatic descent of the bass, and enharmonic change of the seventh into the chord of redundant sixth, No. 7.

This chord strongly indicates the minor mode, yet Haydn introduces it into the modulation of the major mode, and resolves it on the fourth and major sixth, as in No. 8. By which example also it may be seen, that the $^{6}_{4}$, on which the redundant sixth resolves, need not be followed immediately by the third and fifth.



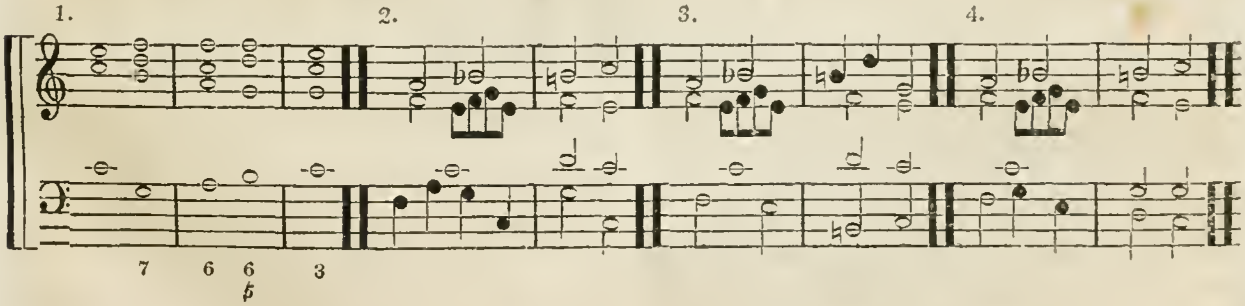
175. M. Choron gives two ways of using the dominant seventh, which he calls irregular procedures (*marches irregulieres*) of that chord. We shall give them in his words.

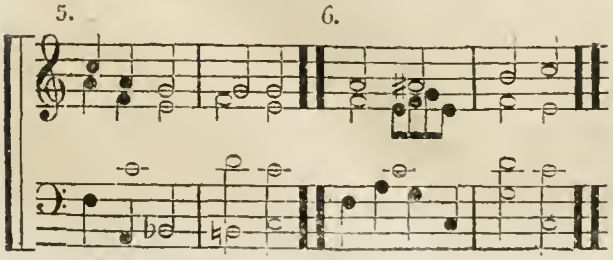
"Besides the movements which we have been examining, which are the most usual of the chord of dominant seventh, there are two others which have not been well examined, and which we shall describe.

"1. The first is the descent of the bass one degree, or by second, which is not employed fundamentally, but which gives a derivative succession of very good effect. It is when the fifth of the key carrying minor seventh rises to the sixth, carrying chord of sixth, and passes thence to the seventh of the scale, which bears the chord of lesser fifth, and resolves on the key-note. The third of the key becomes the final resolution of the seventh of the dominant, which has been holding note during this succession of chords, in which it has been heard alternately as a dissonance and as a consonance," No. 1.

"2d. The second irregular procedure is the descent of the fundamental by fourth, when the dissonance, in place of resolving by descending diatonically, rises by (chromatic) semitone, and thence goes to make a close on the key. This procedure is shown by Padre Sabbatini, in his treatise *Della vera idea delle musicali numeriche segnature*. I give here his examples, such as they are in his work. They are of good effect," Nos. 2—5.

The last four examples, however, appear to us not to belong to the dominant seventh, but to the redundant sixth, as we have written it in No. 6. Since the succeeding chord is the dominant, the bass leaps upwards by fifth, instead of resolving by semitone, in order to avoid doubling the sensible note. So also in the derivative successions we would substitute A※ for B♭.





176. Thus we have endeavoured to make the reader acquainted with the principal combinations used in harmony, consisting of concords, and of such discords as arise by additions to the common chord. There are other discords arising from suspensions and anticipations of the preceding or following chord, or admitted as passing notes on the unaccented part of the measure; and under these names we shall again meet with many of the chords of which we have treated. Perhaps we might, without any great difficulty, bring all discords whatever, not even excluding the dominant seventh,

under these heads. But we have no desire to erect a system. The makers of systems contend pertinaciously for their peculiar ways of exhibiting the progressions of harmony as exclusively right. Our object is to bring the student, as easily as we can, to a clear and practical knowledge of the subject.

CHAP. IX.

OF MELODY—NOTATION OF TIME—AIR AND RECITATIVE—MEASURES AND THEIR DIVISIONS.

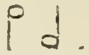
177. Hitherto we have spoken of musical sounds, of different degrees of acuteness or gravity, combined in chords, and heard successively; but we have paid little or no regard to the relative duration of the successive sounds.

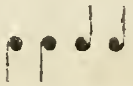
Either harmony or melody may, to a certain degree, exist without any determined order in the successive durations of the constituent sounds; as for instance in the Æolian harp; and such music will, for a certain time, please the ear. It has some of the constituents of good music. The sounds are in good relation in respect of *tune;* but the music is devoid of another essential, rhythm, or order, in the successive durations of the notes.

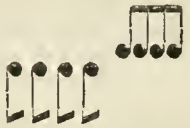
The power of mere rhythmic arrangement, to excite and keep up the attention; to please, and even to interest and arouse the affections; to exhilirate or to affect with sadness in some degree, or at least to accord with that feeling, is most happily illustrated by the effects of the drum; an instrument which has but one note, and that devoid of some of the most pleasing qualities of musical sounds. "Rhythm," says Rousseau, "is an essential part of music, especially of the imitative. Without it melody is nothing, and of itself rhythm is something, as we feel in the effect of drums. Certain passions," he adds, "have a rhythmic as well as a melodious character, absolute and independent of language; such as sadness, which is expressed by slow and equal steps, as well as by languid and low sounds; joy, by springing and quick steps, as well as by sharp and brisk tones."

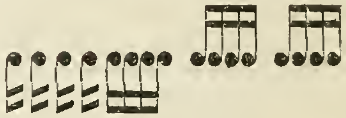
178. The relative duration of musical notes is signified by their form, as in this Table.

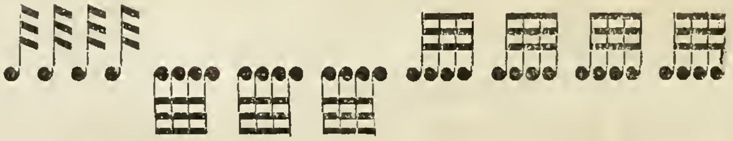
A semibreve

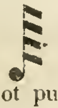
Equal to two minims 

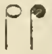
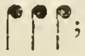
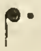
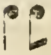
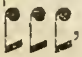
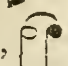
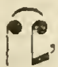
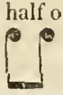
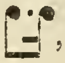
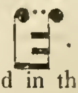
Or to four crotchets 

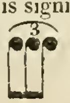
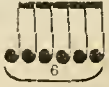
Or to eight quavers 

Or to sixteen semiquavers 

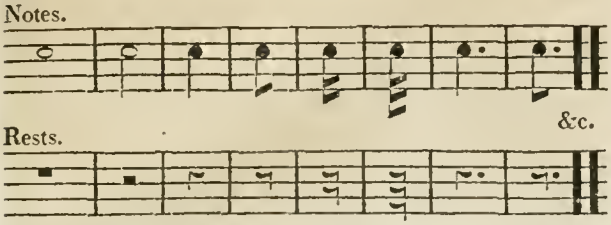
Or to thirty-two demisemiquavers 

In music for the church, there is even a note double the semibreve, called a breve, written thus |=|; and in modern music, in very slow movements, a note half the demisemiquaver .

A dot put after any note makes it half as long again. Thus, is equal to  or to ;  is equal to  or , &c. Frequently, instead of the dot, it is written thus,  , the tie ⌢ signifying that the note is held out during the time of minim and crotchet, &c. without the second note being struck. In modern music, a note is frequently doubly dotted, which gives it also the half of the next shorter note. Thus the time of two quavers  may be made up of a dotted quaver and a semiquaver , or of a doubly dotted quaver and demisemiquaver .

Sometimes three notes are to be performed in the time of two, which is signified by the figure 3 written over or under them; thus,  are to be performed in the time of two quavers or one crotchet. These are called triplets. In a similar manner the figure 6 is sometimes put over six notes, which are to be performed as two triplets, that is, in the time of four; thus  are to be performed in the time of four quavers or two crotchets.

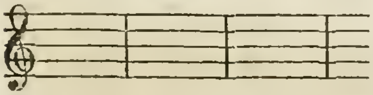
By means of these characters, musicians are able to express every relation in the length of the notes. To these notes there are corresponding rests thus,



179. Melody is of two kinds, Air and Recitative.

Air is characterized, 1st. By rhythm disposed in regularly returning periods, marked by cadences. 2d. By its modulations belonging to a principal key, from which transitions are made into other keys, to which they return, and in which they conclude. 3d. By *subject*, that is, the same or similar turns or phrases in the melody, returning more or less frequently.

Recitative is *measured*, but it has no regularly disposed rhythm; nor does it admit the same variety in kind of measure, or in the division of its measure, which belongs to air. It has no principal key, and it admits more frequent and more sudden changes than would be consistent with the unity of air. Lastly, it has no *subject*, though it has melody. It observes the *intervals* of music, and proceeds from note to note by these intervals; and it is this which distinguishes it as music from ordinary declamation. In speaking, or declamation, no note is held for any time; the voice *slides* from grave to acute, or the contrary; and the terminating sounds of these slides do not form musical intervals, at least not necessarily. Recitative, on the contrary, consists of musical intervals, and its notes belong to musical chords, which proceed according to the rules of harmony; but it is justly called the prose of music. Air is the verse or poetry of music.

180. Every regular piece of music is divided into equal portions of time, called *measures*: these are shown by perpendicular lines drawn through the staff, called bars, thus,  . Hence the measures are vulgarly called bars. These measures correspond to *feet* in poetry. The rhythm of the ancients frequently consisted of feet of unequal quantities; and in the earlier times of modern music, and among the French long after they had been abandoned by others, feet or measures of unequal dimensions were used. But now, universally, the rhythm of music is constituted of equal measures. The time of the measure may be filled up with all the variety of notes; but the sums must in all the measures be equal.

181. All the measures used in music, may be referred to one or other of two principal species, which constitute what are usually called common time and triple time.

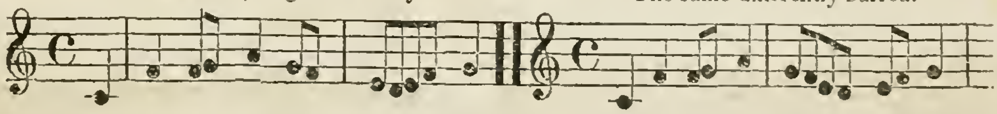
In the former, the measure consists of two or of four equal portions, which we shall with Mr. Kollmann call *principal Times*, though we do not mean to follow his doctrine on this subject, which appears to us both to contain unnecessary distinctions and incorrect representations.

In the latter or triple time, the measure consists of three principal Times.

182. Before we proceed to the more full developement of measures, we must explain the nature of *accent*.

" In the performance of music," says Mr. Holden, " there is a certain emphasis or accent laid on the beginning of every measure, which plainly distinguishes one species of time from another; so that a hearer is naturally led to distribute a tune into its proper measures, though he should take no notice of the manner of beating time, nay though he should know nothing at all of the rules relating to the time of music. We are naturally pleased with equal-timed measures, divided and subdivided in certain eligible manners; but it is a work of time and speculation to ascertain what those divisions are which give us pleasure." " There is no occasion," he adds, " to make the beginning or emphatical part of the measure always stronger or louder than the rest, though it is sometimes best to do so; for it is not so much the superior loudness of the sound as the superior regard which the hearer is led to bestow upon it, that distinguishes one part of the measure from another."

Dr. Callcott very happily illustrates the effect of accent by the following examples, which, though consisting of the very same notes, produce two different effects from changing the place of the bar, so that the accent falls on different notes.


Corn Riggs, original Melody. The same differently barred.

183. To return to the subject of common time, the two kinds of it, viz. that of two principal Times in the measure, and that of four principal Times, are distinguished by the accent. In that of two Times, the first time of the measure is accented, and the second is unaccented.

The measure of two Times consists of two minims or of two crotchets. That of two minims is signified by a large C immediately after the sharps or flats at the clef, as No. 1. That of two crotchets is signified by this fraction $\frac{2}{4}$, which shows that the measure contains two fourth parts of the semibreve, *i. e.* two crotchets, as in No. 2. This is the manner in which this species of measure is most frequently written now a days. It is plain, that the air in No. 1, might be just as well written with two crotchets in the measure, as we have often seen it, and would produce exactly the same effect. Mr. Kollmann, indeed, tells us, that when the measure consists of quick minims, they are to be performed more heavily than slow crotchets of the same length. This, we take it, is an imaginary distinction.

Common time of four principal Times in the measure, is accented on the first and third Times, and unaccented on the second and fourth Times. It therefore contains two principal accents, and, in consequence of this, admits of a formal close on the third Time of the measure, as well as on the first. This, therefore, may be regarded as consisting of two measures of two Times, and may be called a *compound common time* measure. This name, however, we shall find used differently, though in our apprehension improperly. However that may be, this distinction of common time into these two kinds, is not much regarded by some. "The Germans, and also the French," says Dr. Callcott, "consider the measure of four crotchets as a species, different not only from that of three, but even from that of two crotchets; a distinction which arises from the nature of accent, and which is thought of importance by these authors. It is considered by some of them as a simple measure; but it really seems merely to differ from that of two crotchets by the omission of the alternate bar.

This measure is also signified by C immediately after the signature at the clef. An example of this measure is given, No. 3. In this example there is a bar through the mark of common time 𝄵, which is generally explained to mean a brisker movement than the C without a bar. But Mr. Kollmann says that the barred 𝄵 denotes the measure of two principal Times, when the Times are minims, as in No. 1; and the other, the measure of four principal Times, being crotchets, as in No. 3. Whether or no that distinction, in the use of these signs, be generally observed on the Continent, we presume not to say; but they are certainly not so understood in this country. The example, No. 3, is the beginning of a sonata of Beethoven, which seems to contradict Mr. Kollmann's assertion; but as the copy from which we take it is printed in this country, it may be the mistake of the engraver. In justice to Mr. Kollmann, we must add, that in the score of Haydn's symphonies, which now lies before us, this distinction seems to be observed.

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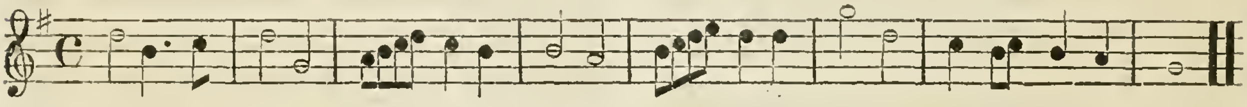

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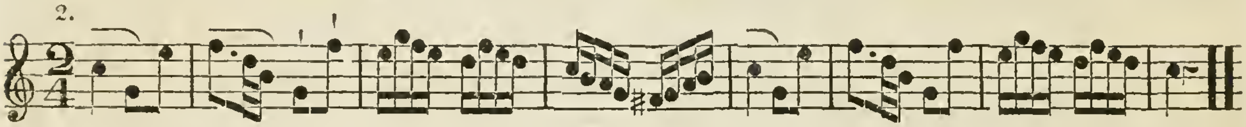

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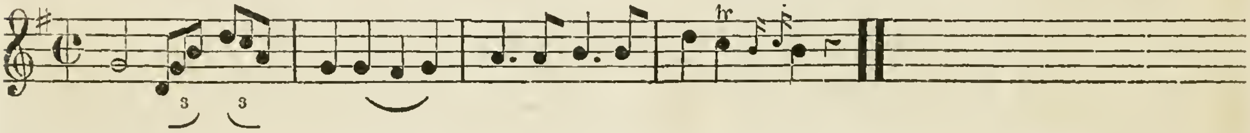

184. In the subdivisions of the measure into smaller notes, the principal Times are still preserved distinct; and the quavers and semiquavers are grouped in such a manner, as to show these principal Times. Thus the two principal Times of the measure are, in No. 1, divided into two quavers each. In No. 2, the principal Times are divided into four semiquavers each. In No. 3, the time of two semiquavers is in triplets, two of which make a principal Time, which, in the third and fourth bar, are written in groups of double triplets, or sextuples, signified by the 6 written over the first group; nor do these two ways of writing make any difference in the performance. In No. 4, the same air, in the minor mode, is varied by divisions into demisemiquavers and semiquavers, the principal Times still distinctly appearing.

These subdivisions of the measure give occasion to an inferior sort of accent at the beginning of each group, to mark distinctly the principal Times, or even the half Times. "These inferior accents," Dr. Callcott justly observes, "which belong to the *Times* of the measure, do not by any means destroy that great and predominant accent that belongs to the first note that follows the bar, and which is accompanied by the THESIS or depression of the hand in beating time. The ARSIS, or elevation of the hand, always follows on the weak part of the measure."

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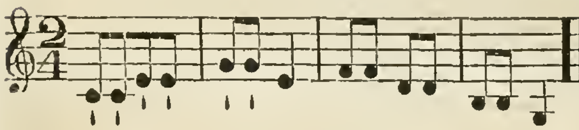

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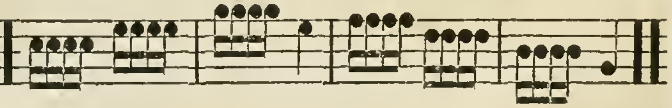

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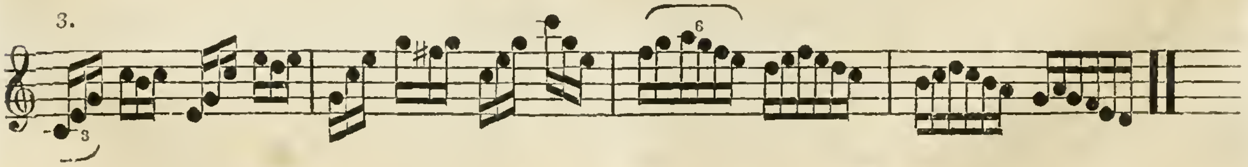

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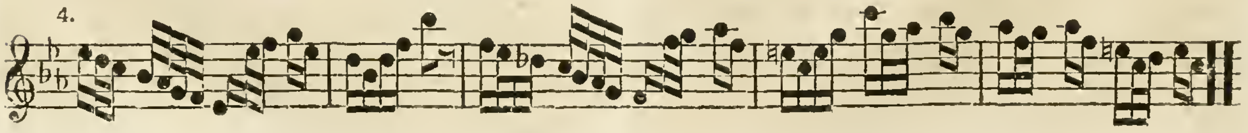

185. Sometimes the composer wishes to give force to the unaccented part of the measure, which Dr. Callcott happily distinguishes under the name of *emphasis*. We cannot illustrate it better than by adopting his explanation and examples.

"In passages like the following, the quavers are often grouped together according to the *emphasis*, and not (as in general) according to the accent, No. 1. In the two first measures of this example, the quavers are grouped according to the *accent;* in the third, according to the *emphasis*, contrary to the accent; and in the fourth the accent again resumes its importance.

"The Italian words *Rinforzando*, *Sforzato*, or their contractions, *Rinf. Rf. Sforz. Sf.* are often used to mark the *emphasis*, and sometimes are placed over accented notes." Mr. Shield explains the difference of these terms thus, *Rinforzando* is the general director to strengthen the tones of a passage; but *Sforzato* is the term when only one note is to be played louder than the rest.

"As every species of measure may be subdivided by accents, according to the degree of quickness in which it is performed; so also the weak parts of every measure may be occasionally made emphatic at the pleasure of the composer.

"To this species of effect may be referred all *syncopated** or *driving* notes, which begin on the *weak* and end on the *strong* parts of the measure. No. 2. In this example the emphasis is on the syncopated *minims*, which begin on the second and end on the third part [Time] of the measure. No. 3. In this example the emphasis is on the syncopated *crotchets*, which begin on the second and sixth, (or the *weak*,) and end on the third and seventh (or the *strong*) parts of the measure."

Sometimes these *driving* passages are continued during several measures in one part, while another part expresses distinctly the Times of the measure, as in No. 4, where, during the first measure, the first and second violins are in unison. In the third and fourth measures, the first violin expresses the Times, while the second violin executes a driving passage, beginning on the second quaver of the second measure, and ending on the seventh quaver of the third. In the fourth and fifth measures, the second violin expresses the Times, and the first has the driving passage. In the sixth measure, both resume the principal Times.

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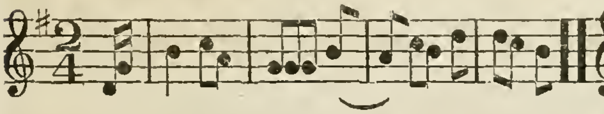

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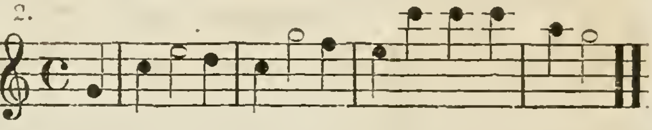

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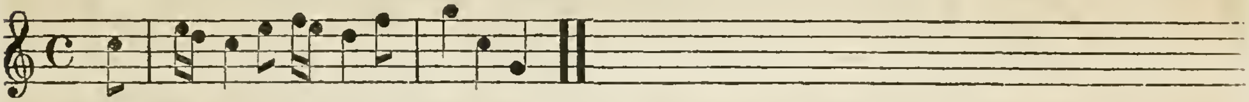

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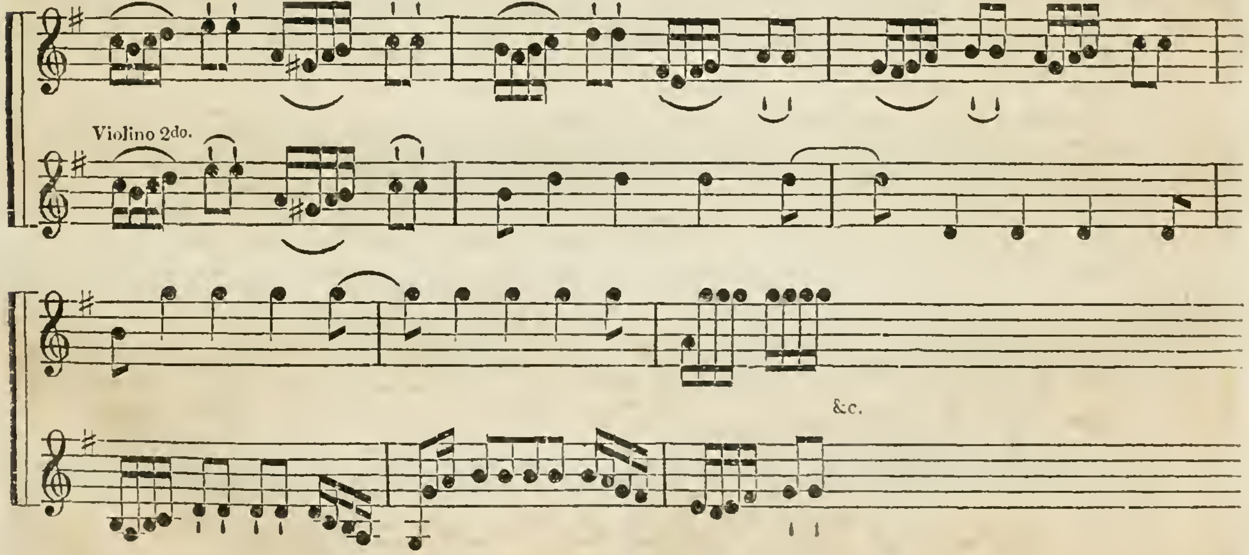

186. Measures of three principal Times are accented on the first Time. The other two Times are unaccented. Some authors indeed say, that the third Time is also accented; and Dr. Callcott says, that the last is rather strong in comparison of the middle Time. The first Time of the measure, however, is certainly the place of the principal accent.

Triple Time is of three minims, or three crotchets, or of three quavers, which are all denoted by fractions, of which the numerator is 3, and the denominator the part of the semibreve, as $\frac{3}{2}$, $\frac{3}{4}$, $\frac{3}{8}$, Nos. 1, 2, 3. Sometimes the triple measure is simply denoted by the figure 3, as in No. 4. The subdivision of the principal Times of triple measures is generally by continual bisection, as in measures of Common time; see No. 3, in which the quavers are subdivided into two semiquavers, or four demisemiquavers, the groups showing the principal Times. The principal Times are also frequently in triplets, as in No. 4. In No. 5, the principal Times of the two last measures are in sextuples, or triplets for each half Time. In No. 6, the fourth and sixth measures are driving passages, beginning on the second half of the first principal Time, and ending on the first half of the third principal Time, while the bass expresses the principal Times distinctly.

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* This word will be explained in the next chapter.

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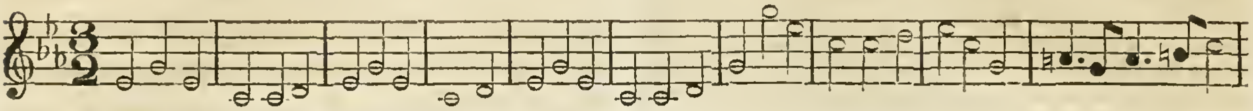

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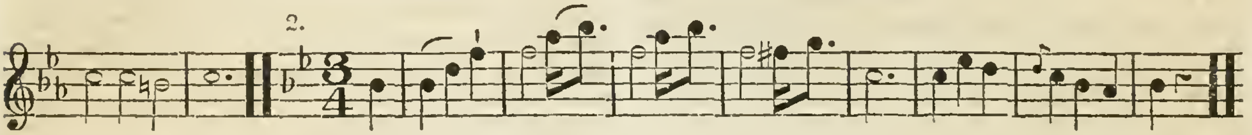

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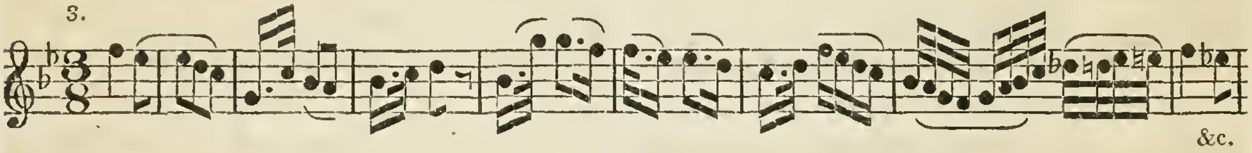

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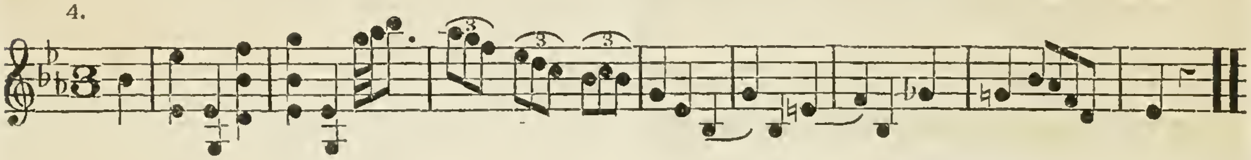

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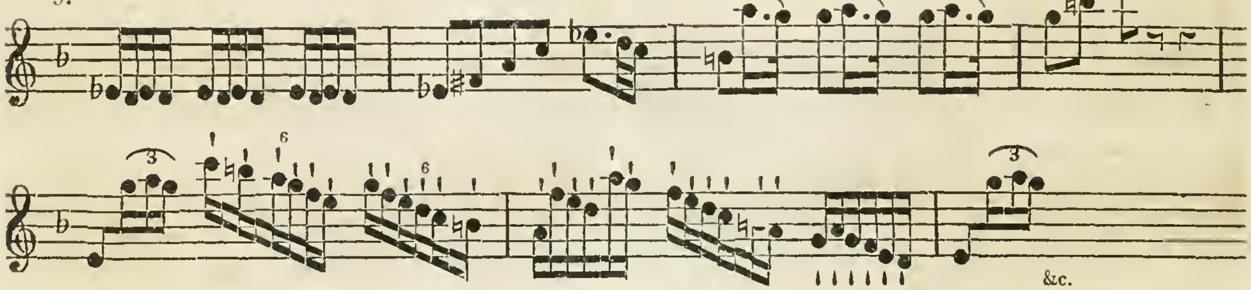

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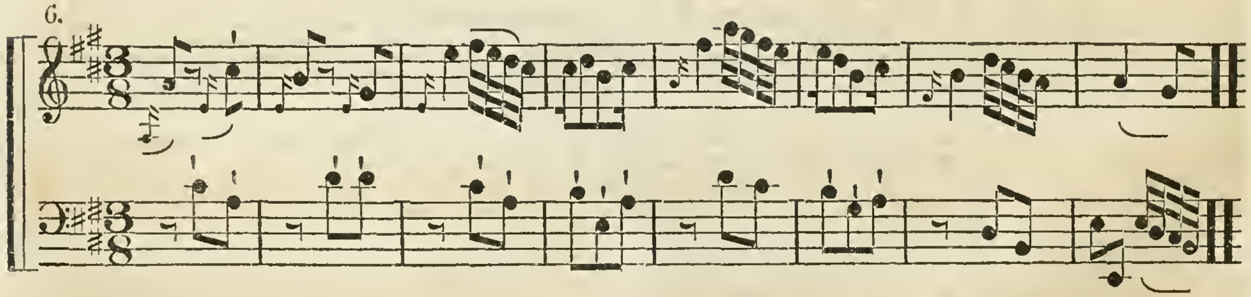

187. Two measures of three principal Times united, form what is usually called *Compound common time.* *Common*, says Dr. Callcott, because every measure is equally divided; and *compound*, because each half is a single measure of triple time. Though we are not fond of disputing about words, we cannot help remarking, that this name of compound *common* time is not justified by the circumstance, that the compound or double measure is equally divisible. This measure, in our opinion, ought not to be confounded with the triplet, into which the principal Times of two or four in a measure are sometimes divided. These triplets are felt as single Times of the measure, and the impression of equal time remains; but in the compound time of which we are speaking, the principal Times of each half measure are the same as in triple time, and are themselves susceptible of all the subdivisions of that measure; and the impression of triple time is never lost.

In this compound measure there are two principal accents, one at the beginning and one at the middle of the measure; therefore it admits of a full close in the middle of the measure.

This compound measure is written either in crotchets or quavers, denoted by $\frac{6}{4}$ or $\frac{6}{8}$, being, as before, fractions of the semibreve, Nos. 1 and 2. Sometimes, by the omission of a bar, the latter becomes a measure of twelve quavers, or four simple measures of three quavers, denoted by $\frac{12}{8}$, No. 3.

"The omission of the bars," says Dr. Callcott, "makes some difference in the appearance of the music, and influences the counting according to the degree of quickness in which the piece is performed. But in other respects, the division of the measure has no power of altering the real nature of the time or tune [air]; nor can the auditor perceive whether the triple time performed be expressed by the figures $\frac{12}{8}$, $\frac{6}{8}$, or $\frac{3}{8}$."

The principal Times in these compound measures are susceptible, as we have said above, of all the subdivisions of triple measures. Thus in No. 4, the quavers are divided into two semiquavers, or triplets of semiquavers, or into four demisemiquavers.

These subdivisions of the Times decidedly distinguish this $\frac{6}{8}$ measure from the triplets which occasionally occur in common time. When triplets are continued throughout a movement of considerable length, the impression of common time will be in a great measure lost. No. 5 is the subject of the finale of one of Haydn's symphonies, in which the first violin, and most of the accompaniments throughout, move in triplets, with hardly any exception, which will be felt by the auditors as $\frac{6}{8}$ compound time. The crotchets in the second violin part may easily be understood as pointed; nor is the division of the third and seventh measures sufficient to maintain the impression of common time. The conclusion of the first strain is given at *b*, where the two last measures will be felt as consisting of pointed crotchets equivalent to one half of the compound measure of $\frac{6}{8}$ time. Mr. Shield observes, that $\frac{2}{4}$ denotes the simple, and $\frac{6}{8}$ the compound time, which are frequently played together; and he gives the example, No. 6, in which the upper part is marked $\frac{6}{8}$, and the bass $\frac{2}{4}$. With all our respect for that excellent master, we cannot approve of this confounding of these different species of measure. If the principal part continue to move in compound time, it is easy to write the accompaniment in a corresponding manner, without any alteration of the effect, as at *b*. If by the division of the principal Times the impression of common time be established, then ought the upper part to be marked $\frac{2}{4}$, and the triplets denoted by 3, or left to the sagacity of the performer to understand from the grouping.

By means of such examples, some endeavour to show that all measures whatever are only modifications of common time. But the distinction of common and triple measures is one of the most important and characteristic circumstances in melody; so that we cannot help thinking the ingenuity which is exerted to make these the same, very unprofitably directed.

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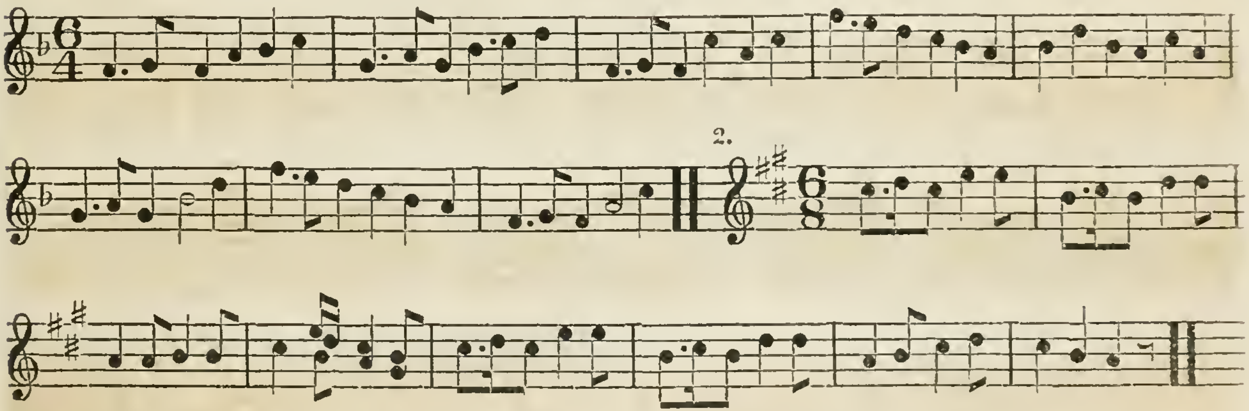

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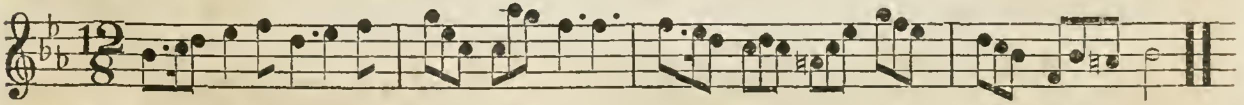

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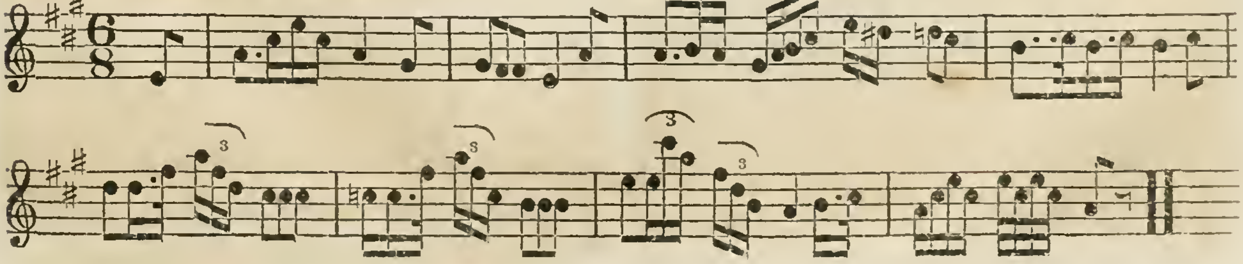

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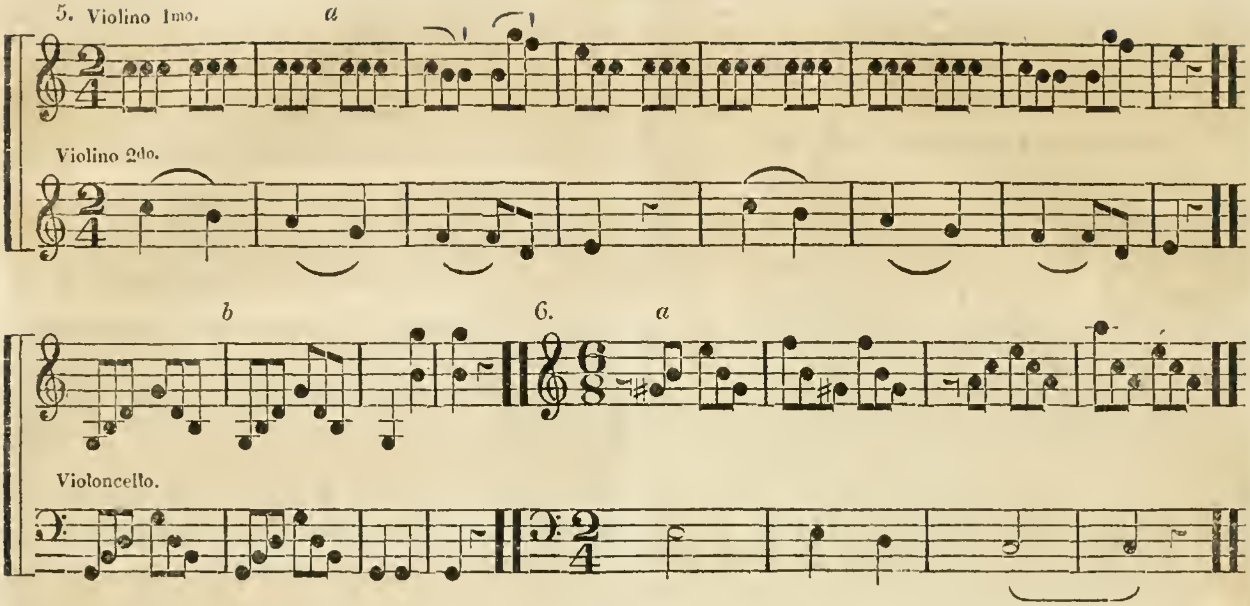

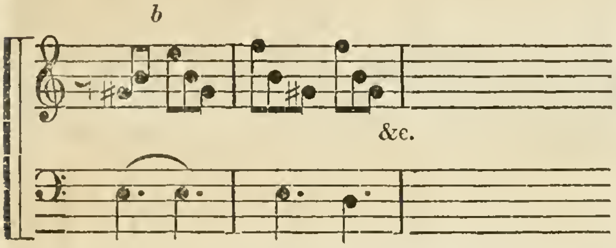

188. There is yet another species of compound time, consisting of three simple measures of three principal times, which is, however, seldom met with in modern compositions. It is not unfrequent in the national airs of Scotland and Ireland, as No. 1. In this measure there are three principal accents, namely, one at the beginning of each of the three simple measures. It is denoted by a fraction of the semibreve, as $\frac{9}{8}$ or $\frac{9}{16}$, No. 2.

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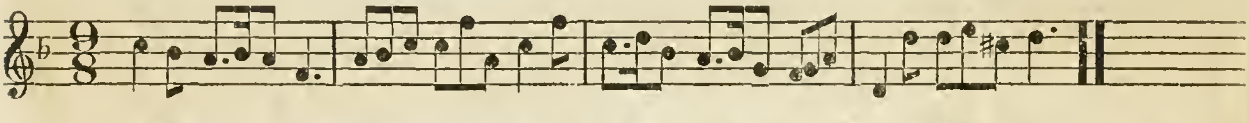

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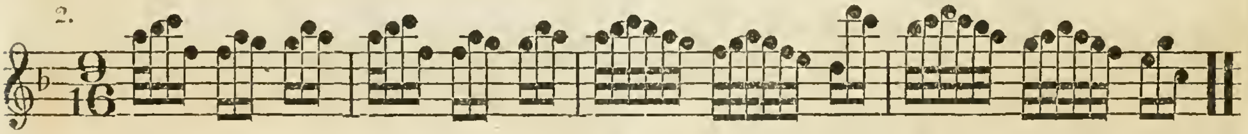


CHAP. X.

OF DISCORDS BY SUSPENSION AND ANTICIPATION—PASSING NOTES, DIATONIC AND CHROMATIC.

189. Having explained the different measures used in music, and the nature of accent, we shall defer the farther investigation of melody, and in the present chapter endeavour to exhibit specimens of those chords, which, by Kirnberger and his followers, are called *accidental chords*, and in the French school *artificial chords*. Under the latter name, indeed, the French (Messrs. Catel, Choron, &c.) comprehend all discords which require preparation; consequently many chords of the seventh, which Kirnberger, Kollmann, &c. call *essential*, and which we have treated of under the name of the subdominant seventh. These, we have already observed, might be very well explained as *suspensions*. It is to this subject that we are now to direct the student's attention.

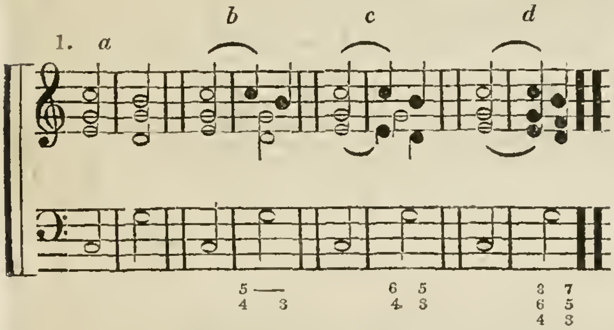
190. When in the succession of one chord to another, one or more notes of the preceding chord are continued for some part of the time of the succeeding chord, and then proceed diatonically to the notes of the second chord, whose place they have occupied, this is called a *suspension* or *prolongation;* and if the suspended note be dissonant to the bass, its falling or rising diatonically to the concord is called its resolution.

Thus, if in going from the tonic harmony to that of the dominant, instead of striking all the notes of the latter immediately, as No. 1, *a*, we continue the octave of the first chord as 4th to the bass, as at *b*, this note *suspends* or *retards* the 3d, which is the proper note in the dominant chord; and if at the same time the third of the tonic chord be continued, as at *c*, we have a double suspension, the 4th retarding the 3d, and the 6th retarding the 5th. These are suspensions, because they are foreign to the dominant chord, and they are treated as dissonant. But the fifth of the tonic, continued as octave in the dominant chord, is not properly a suspension, because it belongs to the harmony. Yet even this may be treated as a suspension of the 7th, as at *d*.

The general rule for discords of suspension is, that they must be prepared on the unaccented part of the measure, struck on the accented, and resolved diatonically on the unaccented.

The prolonging of a note commenced on the unaccented into the accented part of the measure, is also called a *syncopation*. This word is therefore synonymous, or nearly so, with suspension. "The discords of *syncopation* only differ from those of suspension," says Dr. Callcott, "by constituting part of the radical harmony, and by not being merely appoggiaturas.

"The diatonic sequence of sevenths is one of the principal passages in which these discords are used." Though we do not think the distinction of much importance, it seemed necessary to explain a term so frequently used by musicians.



191. The discords of suspension are in the upper parts the seventh, the ninth, the fourth or eleventh, the sixth or thirteenth; and in the bass, the second. We shall follow M. Choron, in giving a summary view of the most ordinary ways of preparing, accompanying, and resolving these discords, and afterwards we shall consider these suspensions as taking place in the principal progression of harmony, both fundamental and inverted, which will present the same discords in different lights, and variously combined with each other.

192. The seventh is prepared with all the consonances, that is to say, with the octave, the third, the fifth, and the sixth. It is resolved on the sixth, the bass continuing in the same degree, or on the third when the bass rises fourth, or descends fifth.

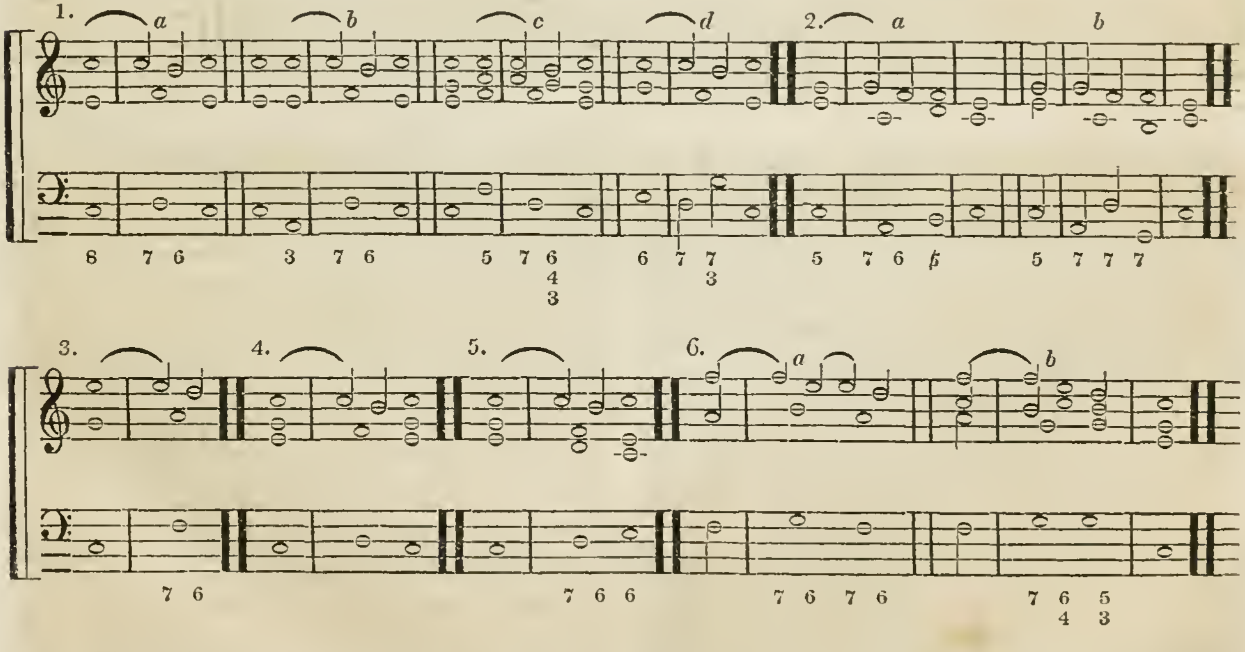
It is prepared in the octave when the bass rises one degree, as from the key to the second, No. 1, *a*. It is prepared in the third when the bass rises fourth, as No. 1, *b*, and No. 3. It is prepared in the fifth when the bass descends third, as No. 1, *c*, No. 2, *a*, *b*. Lastly, it is prepared in the 6th when the bass descends diatonically, as No. 1, *d*.

In three parts, the seventh is accompanied with the third, as in the above examples. In four parts, the third may be doubled, as No. 4; or the octave may be added, as No. 5; or the fifth, as No. 1, *c*.

It is plain, that these chords are the same of which we have treated in Chap. IV. Those in No. 1, *a*, *b*, *c*, *d*, are the subdominant seventh on the second of the major scale. No. 2, *a*, is an inverted sequence from the sequence of sevenths, as shown at *b*. No. 3 is the major seventh, and may be part of the sequence of 7th and 6th, already explained, Art. 132—135.

After the same manner, all other chords of the seventh, not excepting the dominant seventh, when prepared at least, may be considered as suspensions, as in No. 6, *a*, *b*.

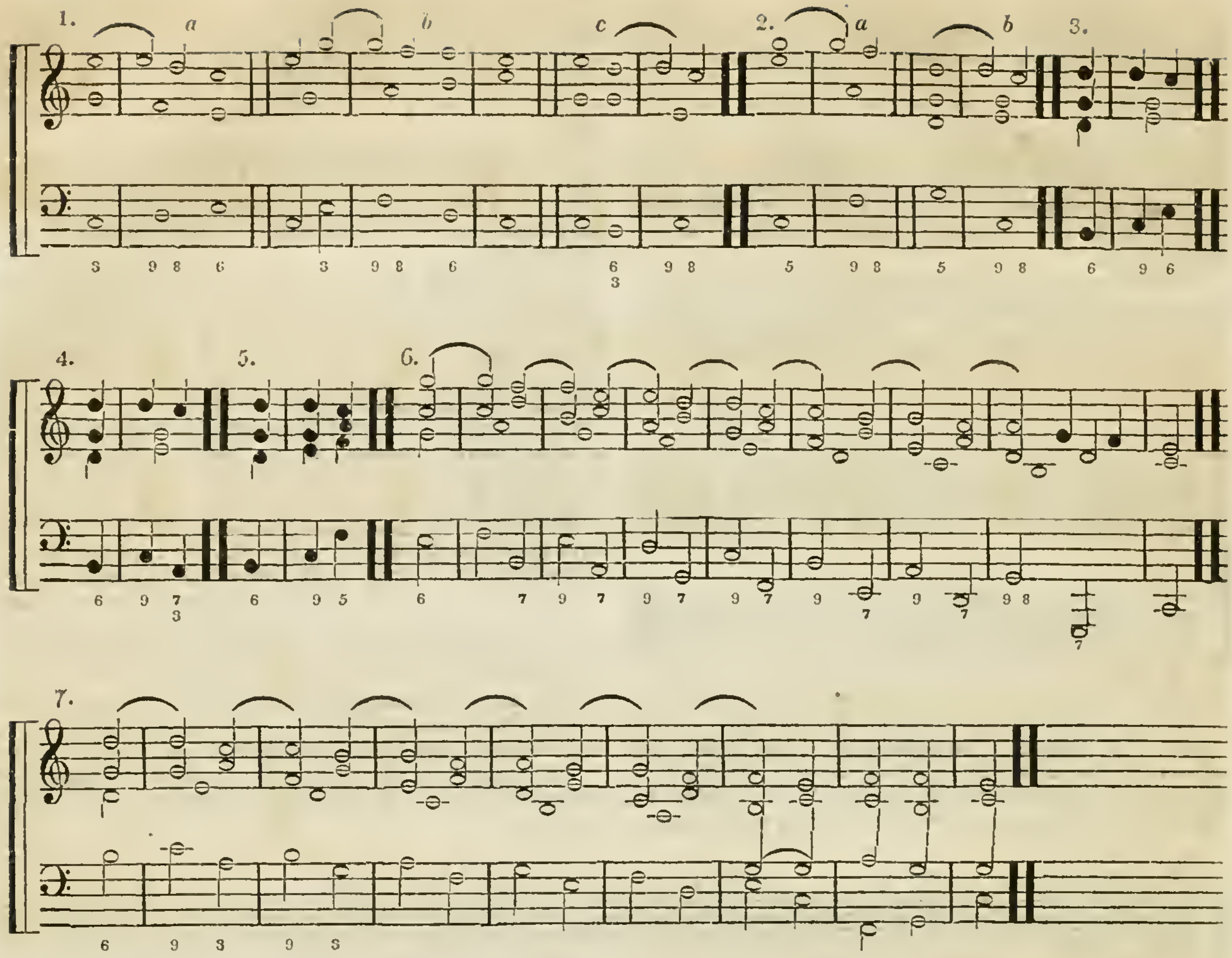
The major seventh is frequently resolved by ascending diatonically, as we shall see in the suspensions of the dominant chord.



193. The ninth is prepared by the third or by the fifth. Mr. Shield tells us, that when any of Corelli's pupils prepared it by an eighth, he used to cry out *cattivo*, which signifies *bad*.

The ninth is resolved by diatonic descent of one degree. If the bass be stationary, it will resolve on the octave; if the bass rise a third, the resolution will be on the sixth in the first inversion of the same chord; if the bass descend third, the resolution will be on the third of a new chord; if the bass rise fourth, it will be on the fifth of a new chord.

In three parts it is accompanied with third or tenth, and in four parts with third and fifth. The examples require no illustration, 1—5.



The ninth added to the dominant chord we considered formerly as a fundamental chord; and ninths added to the other common chords of the scale, might be considered as such with as much reason as the sevenths. In No. 6 we give a sequence of ninths and sevenths alternately; and the student may take both as suspensions, or as essential and fundamental chords, as he chooses. No. 7 is a sequence of ninths and common chords alternately, which is derived from the other.

When the ninth is the fifth of the dominant chord suspended, it may resolve upwards on the third of the key. In this case it is often figured by 2. But the characteristic distinctions of the second and ninth will be explained by and by.

The seventh and ninth are frequently used as double suspensions, as will be seen afterwards.

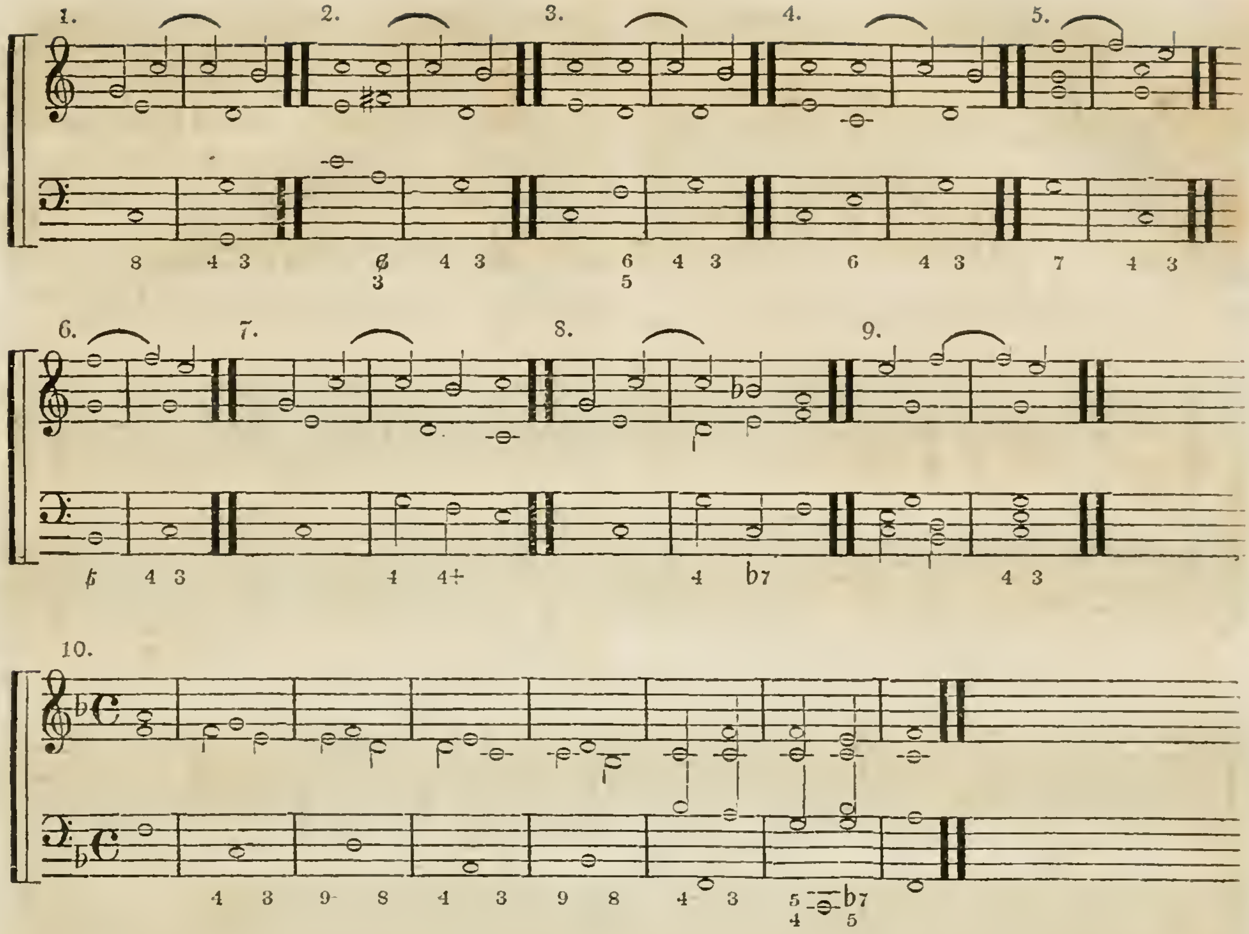
194. We shall copy literally M. Choron's examples and observations respecting the discord of fourth or eleventh.—"The fourth is prepared with all the consonances, that is to say, the octave, the third, the fifth, and the sixth. The fourth will be prepared by the octave when the bass falls by fourth or rises by fifth, as from the key-note to the fifth, No. 1. It will be prepared by the third, the bass descending one degree, as from the sixth to the fifth of the key, No. 2. It will be prepared by the fifth when the bass rises one degree, as from the fourth to the fifth of the scale, No. 3. Lastly, it will be prepared by the sixth, the bass rising third, as from the third to the fifth of the key, No. 4.

"The fourth may also be prepared by the minor seventh and by the minor fifth: the former takes place when the fifth rises or falls to the key-note, No. 5; the second takes place when the seventh (or leading note) rises to the key, No. 6.

"That the fourth may be dissonant, it must be accompanied with the fifth. It is the shock of these two notes which really occasions the dissonance; for the fourth alone, or accompanied by the sixth, is not dissonant."

We must, however, here repeat what we have formerly observed, that the fourth to the bass is of itself felt to be dissonant, so far at least as to raise the expectation of a succeeding third on the same bass; and the fourth and sixth as much raises the expectation of third and fifth as the dominant seventh does of the succeeding tonic harmony. We mean not to dispute about words; but we consider it an observation of importance to the student, that the chord of fourth and sixth does not admit of so free a use as the first derivative of the common chord. But to return to M. Choron.

"The natural resolution of the fourth is on the third, as we have seen in the preceding examples; yet it may also resolve on the greater fourth, No. 7; or on the minor seventh, No. 8.



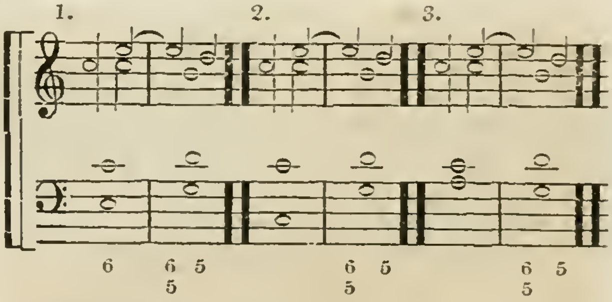
" One conceives from these examples, that there may be a great many ways of varying these resolutions. The dissonance of fourth may in general be placed at the distance of fourth. But when it is accompanied with the note of its resolution, that is to say, by the third brought in by contrary motion, then it must be at the distance of eleventh, that it may be ninth to that third." See No. 9.

To these quotations we shall add the following from Mr. Shield. " The fourth accompanied with the fifth, is a discord that was as much used by the best harmonists of the last century, as it has been by every class of composers in this. When it is introduced on a resting bass, it resolves into the third. Its effects so much resemble the ninth followed by the eighth, that they are frequently introduced alternately in uniform strains," No. 10.

The 7th, 9th, and 4th or 11th, are often used together as triple suspensions, as we shall afterwards see.

195. " The dissonance of the thirteen," says M. Choron, " is little known, because it is little used, not being suitable either for the severe style, or the free style of music. For this reason its theory is still in its infancy: the ancients have not so much as spoken of it, and the moderns seem to have treated it but superficially. This discord is practised usually on the fifth of the key. It is prepared by the octave, by the third, and by the fifth.

" To prepare the thirteenth by the octave, the bass must rise by third, as from the third to the fifth of the key, No. 1. To prepare it by the third, the bass will rise by fifth, No. 2. Lastly, to prepare it by the fifth, the bass will descend one degree, as from the sixth of the scale to the fifth, No. 3. One sees that the *retardation* prevents the fifths. This preparation is the least used.



" This discord ought to be accompanied by the fifth brought in by contrary motion; and this obliges us to have recourse to an accompaniment in dispersed harmony. It is necessary also to add the third, otherwise the harmony would be too meagre, so that this discord is not used except in four parts. These two circumstances concur to render the employment of this discord still more rare.

" The most ordinary resolution is on the fifth; yet it may also take place on the third, the bass rising third as in the former cases."

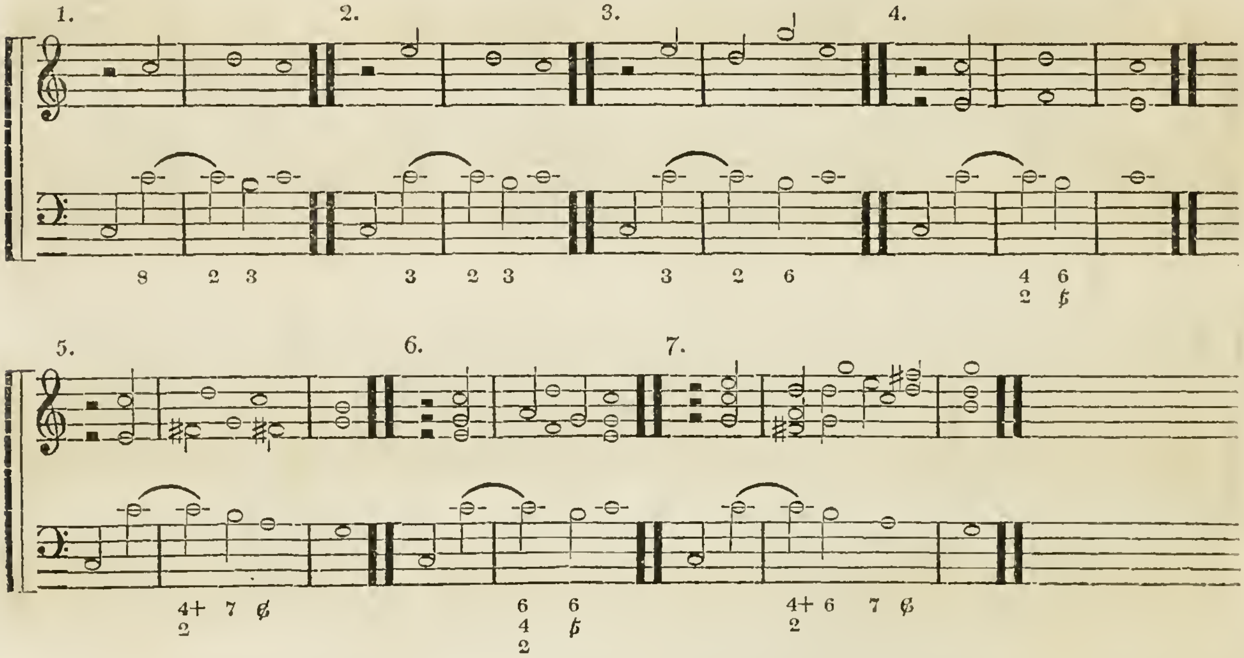
So far M. Choron. The name, however, of the chord of the thirteenth, is given to a chord of a very different nature, viz. to the chord of seventh on the sensible note taken over the tonic bass, as we shall afterwards see. We have also seen two chords of the thirteenth, being the last derivatives of the dominant chords of 7th and 9th major and minor. Art. 155, No. 7—160, No. 7.

196. "The second is a discord which belongs exclusively to the bass. It differs from the 9th, 1st. In being prepared and resolved in the bass. 2dly, That it may be practised at the real distance of second, whereas the 9th must be at the real distance of 9th. In three parts the second is placed at the distance of 9th, in order that the two notes which form the shock may be in the extreme parts. The third part is intermediary.

"The second is prepared in all the consonances; but the best preparation is by the octave, or the third, because the upper part proceeds diatonically, Nos. 1, 2. The most ordinary resolution is on the third, as in these examples; but it may be also made on the sixth, No. 3, or any other consonance. In three parts the second is accompanied with the perfect fourth, or greater fourth, according to circumstances. Nos. 4, 5.

"In four parts the sixth is generally added, and this sixth descends diatonically at the same time with the bass. Nos. 6, 7."

The student will easily recognize Nos. 1, 2, 3, 4, and 6, as the third derivative of the subdominant chord of seventh proceeding to the dominant; and Nos. 5 and 7 as the third derivative of a dominant leading to the fifth of the key.



We shall now exhibit specimens of the suspensions practised in the principal harmonical progressions.

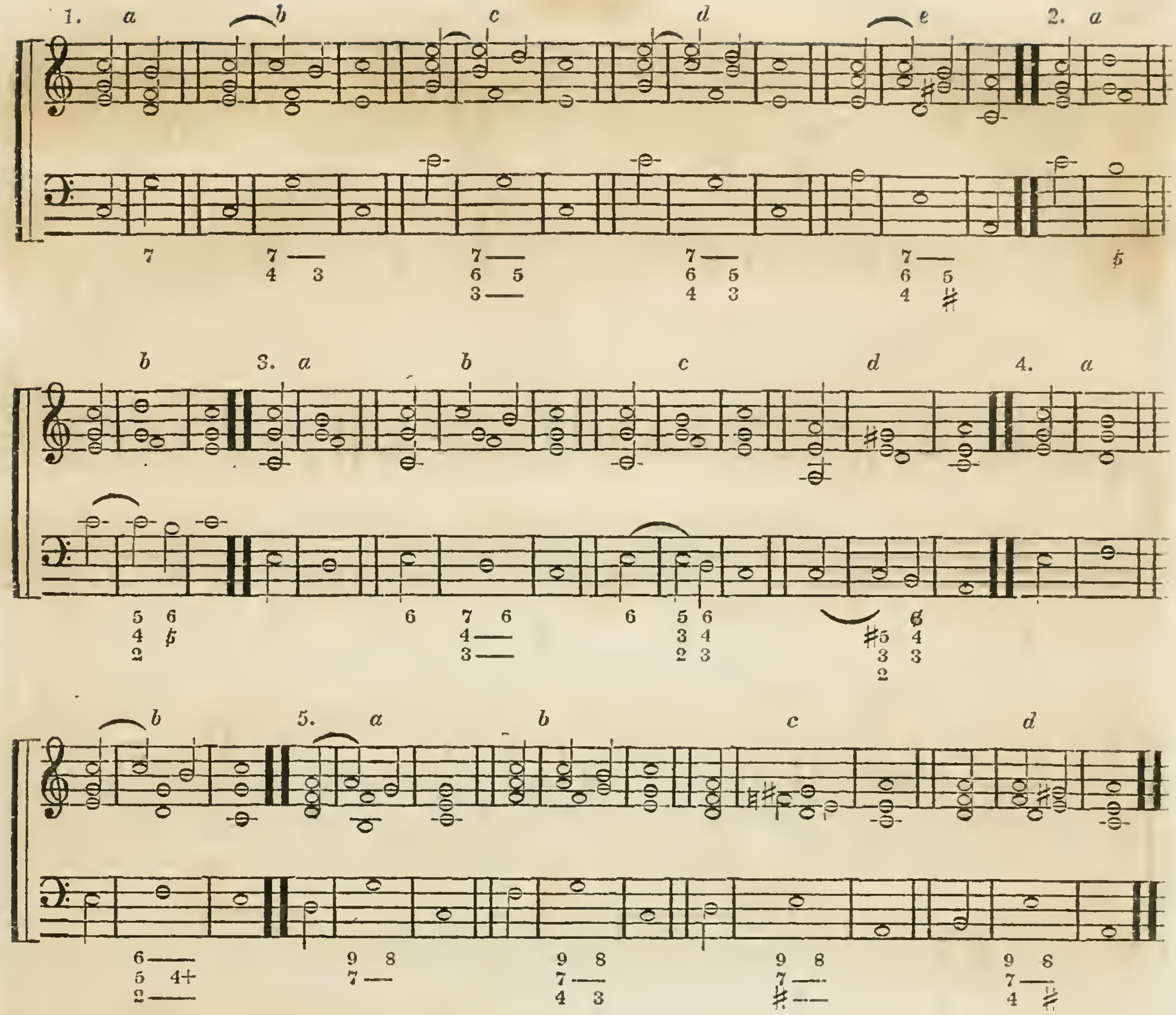
197. We have already, Art. 190, *b*, *c*, *d*, exhibited the suspensions which may be practised in passing from the tonic to the dominant common chord. When the 7th is added to the dominant chord, other chords arise out of these suspensions. Thus, if instead of going at once to the dominant chord of 7th, as No. 1, *a*, the key-note be continued on the accented part of the measure, we have the chord of fourth, fifth and seventh, retarding the true dominant, as at *b*. If the third of the tonic be continued, we have a chord of third, thirteenth or sixth, and seventh, as at *c*; and if both be continued, we have fourth or eleventh, sixth or thirteenth, and seventh retarding the third, fifth, and seventh, as at *d*. In the minor mode, this chord of the thirteenth is less harsh, as the interval from the 7th to the 13th is minor 7th, as at *e*.

No suspension can well be practised in going from the tonic harmony to the first inversion of the dominant chord of seventh, except that of the bass, which produces the chord of $\begin{smallmatrix}5\\4\\2\end{smallmatrix}$, as at No. 2, *b*; or of $\begin{smallmatrix}6\\4\\2\end{smallmatrix}$, as in Art. 196, No. 6. We shall have occasion to notice the dominant harmony taken over the key-note more particularly by and by.

In passing from the tonic harmony to the second derivative of the dominant seventh, as No. 3, *a*, the suspension of the key-note produces a chord, consisting of third minor, perfect fourth, and minor seventh, which last resolves on the major sixth, as at *b*. In the same progression, the bass of the first derivative of the tonic is often suspended, which, in the major mode, produces a chord consisting of minor second, minor third, and perfect fifth, as at *c*. In the minor mode the second and third are major, and the fifth redundant, as at *d*. Notwithstanding of the harshness of this last interval, the whole combination is less harsh than in the major mode.

In passing from the tonic harmony to the third inversion of the dominant, the key-note may be suspended as a fifth retarding the greater fourth, as No. 4, *b*.

In preparing the dominant by the subdominant chord, by prolonging the sixth of the scale, we have the dominant $\begin{smallmatrix}9\\7\end{smallmatrix}$, formerly explained, as at No. 5, *a* and *c*; and if at the same time the key-note be prolonged, as at *b*, *d*, we have the chord of $\begin{smallmatrix}9\\7\\4\end{smallmatrix}$. After the same manner, in preparing the first derivative of the dominant by the subdominant chord, we have, by suspending the sixth of the key, the chord of minor 7th on the sensible note in the major mode, and the chord of diminished seventh in the minor, retarding the $\begin{smallmatrix}6\\5\!\!\!/\end{smallmatrix}$, No. 6, *a*, *b*. In going from the subdominant to the other derivatives of the dominant, we cannot have any suspensions, because the bass note then belongs to both the chords.



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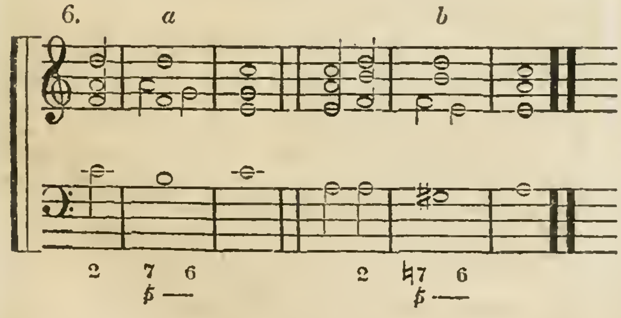
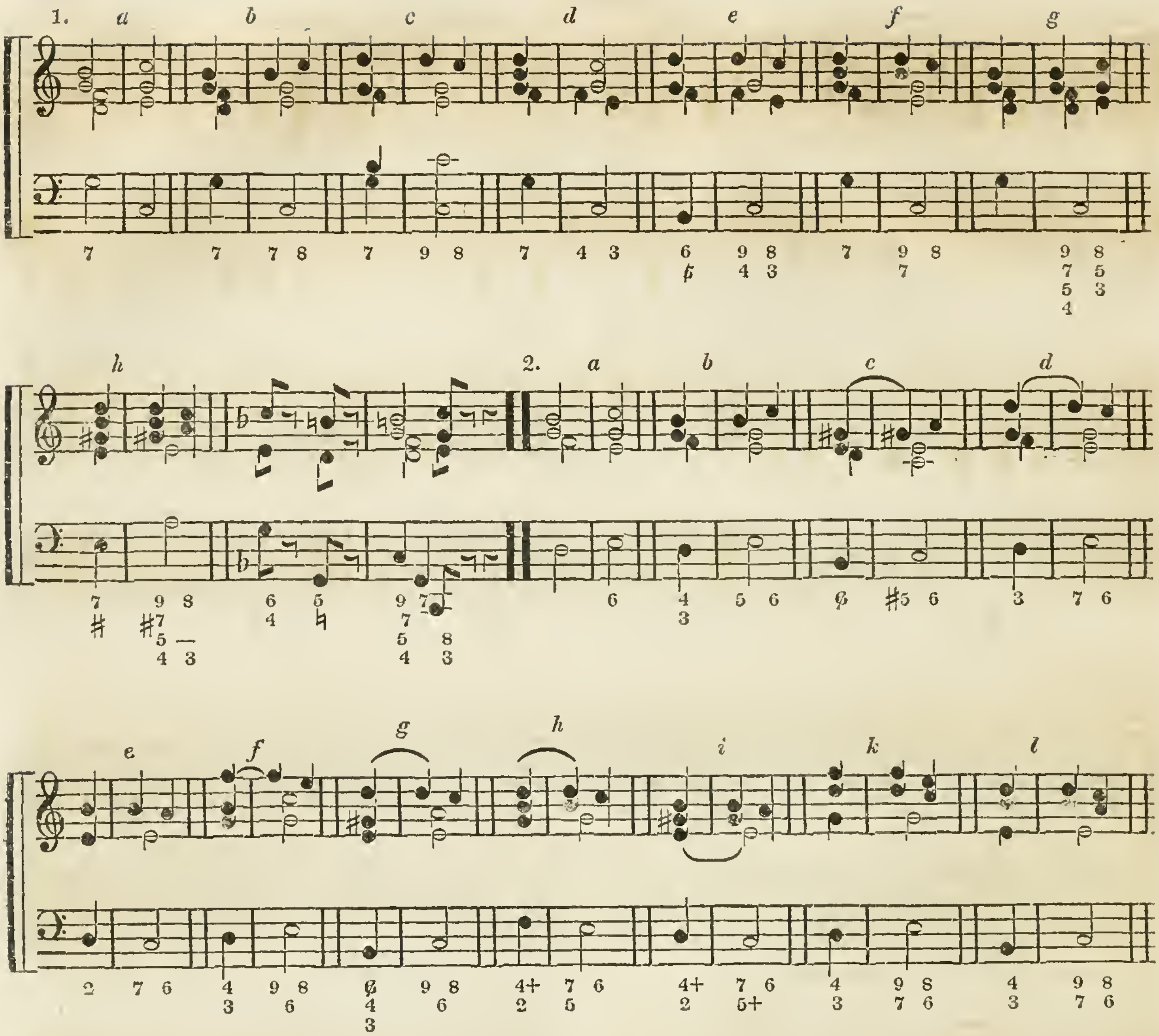
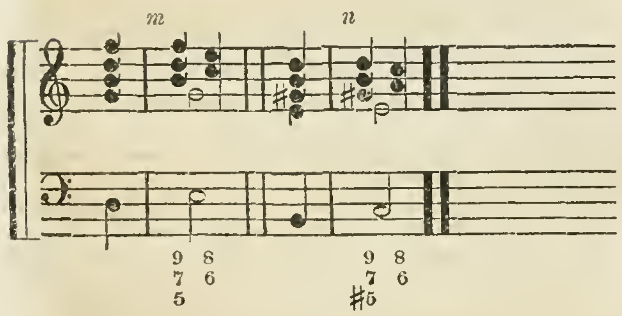


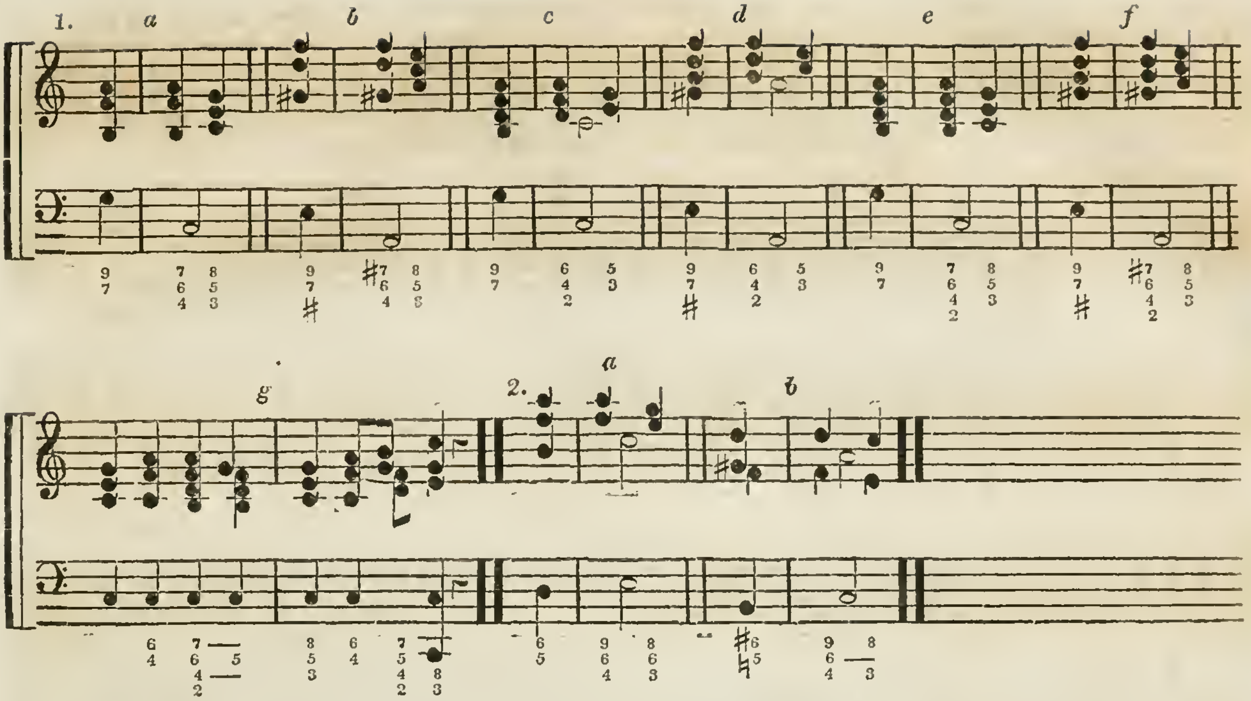
198. Any part, or the whole of the dominant chord of seventh, may be suspended on the key-note before the resolution. The third of the dominant suspended gives a chord of major seventh, and the 7th being the sensible note, must rise to the resolution, as at No. 1, *b*. The fifth suspended gives on the tonic a chord of 9th, and this generally resolves downward on the octave, as at *c*; but it sometimes rises to the 10th, and, as on a resting bass it is often taken at the distance of a second, it is very usual to figure it by 2. The dominant 7th suspended, gives a chord of 4th and 5th on the tonic, as at *d*. These suspensions may be taken in pairs, as $\frac{9}{4}$, $\frac{9}{7}$, *e*, *f*; or all three together, as at *g*, *h*. The whole chord is sometimes struck on the tonic, although only part of it was heard in the preceding chord, as in the example from Mozart, at *j*, where also the bass takes the dominant again before the final resolution.

The resolution of the dominant chord on the chord of sixth, also gives suspensions worth the attention of the student. The suspension of the sensible note gives a 5th, retarding the 6th, as in No. 2, *b*; and in the minor mode this fifth is redundant, as at *c*. The suspension of the fifth of the dominant chord of seventh, gives a seventh, retarding the sixth, as at *d*. In the minor mode this seventh is major, as at *e*. If the discord be suspended, while the rest of the dominant is resolved, we have a chord of sixth with a ninth retarding the octave. In the major mode the 9th is minor, as at *f*; in the minor mode it is major, as at *g*. These suspensions may be taken in pairs, as at *h*, *i*, *k*, *l*; or all at once, as at *m*, *n*.





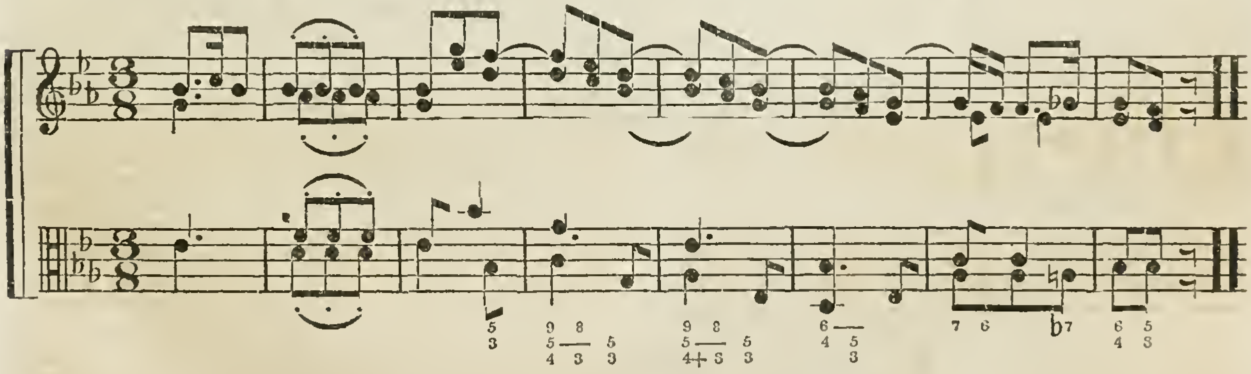
199. The resolution of the dominant chord of seventh and ninth major and minor; or of the chord of lesser fifth and seventh on the sensible note in the major mode, and diminished seventh in the minor mode, furnish chords by suspension worthy of particular notice. The seventh, ninth, and sensible note suspended on the tonic, give a chord of 4th, 6th, and major 7th, retarding the 3d, 5th, and 8th. The fifth, seventh, and ninth, give a chord of second, fourth, and sixth. M. Choron says, the fifth of the dominant ought not to be suspended along with the ninth, because they would form 9th and 13th, which would make fifths by the resolution. But the fifth of the dominant may rise (as in this suspension it generally does) to the third of the key, as in our examples *c* and *d*, for which reason it is better to figure it by 2; or the thirteenth may be resolved before the 9th or 2d, as in the example at *g*. The suspension of the whole chord of seventh on the sensible note, gives a chord consisting of second or ninth, fourth or eleventh, sixth or thirteenth, and major seventh. This is usually called the chord of the thirteenth, and is frequently introduced on a resting bass, as in the example at *g*; as we shall see by and by, under the name of Organ Points. These chords, resolving on the chord of sixth of the tonic harmony, also afford by their suspensions two chords of 4th, 6th, and 9th, No. 2, *a*, *b*, retarding the 3d, 6th, and 8th.



200. We have said, Art. 112, that one common chord may rise diatonically to another common chord by the opposite motion of the parts; and we there gave an example of a regular progression of the bass falling 4th and rising 2d. In such a progression at the diatonic rise of the bass, the third and eight are often retarded by the fourth and ninth, as in the following beautiful example from Mozart's first quintetto, Pleyel's edition. The greater fourth, the reader will observe, is used to retard the third in the same manner as the perfect fourth. The effect of these suspensions in softening down the diatonic progressions of one common chord to another, is very striking and agreeable. Compare the example, Art. 112.

Before quitting the subject of suspension, we may observe that suspensions in the bass, such as Art. 197, No. 3, *c*, *d*; Art. 199, No. 1, *g*, are what Rameau called chords of supposition. Rousseau having explained the preparation and resolution of chords of supposition by syncopation, adds, that these chords of supposition, well examined, may all pass for mere suspensions; so that the system of Kirnberger and his followers is not so original as they would have us believe.

The chords of suspension are so numerous, that it is impossible to enumerate them all. The specimens we have given, are sufficient to enable the student to understand them when he meets with them. We recommend those which we have exhibited to his particular study, as being the most usual and most important.

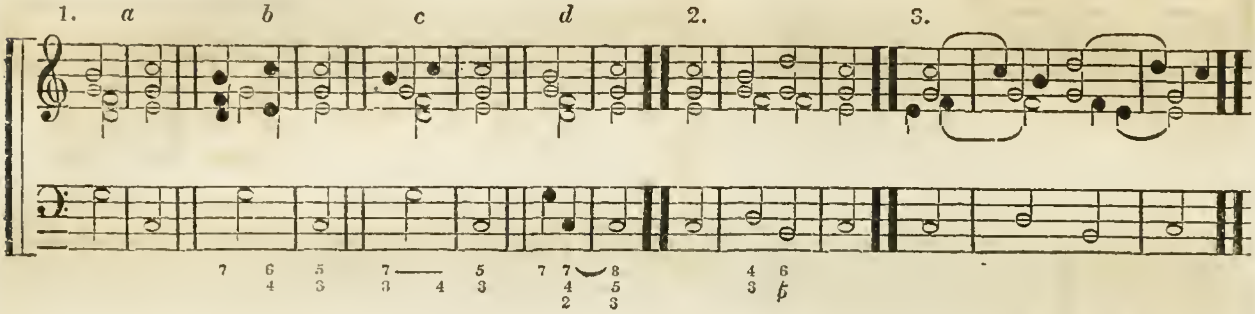


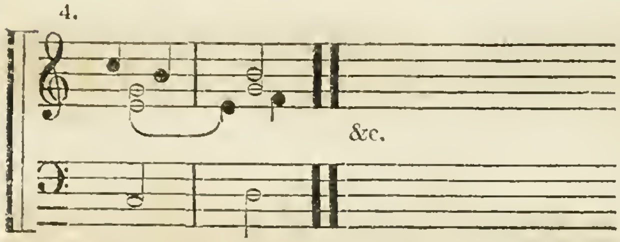
201. *Anticipation*, or, as Mr. Kollmann calls it, *interruption*, takes place when in a natural progression, as, for instance, the resolution of the dominant on the tonic, as at *a*, one or more notes of the second chord are taken in the time of the preceding one, as at *b*, where the upper parts, resolved by *anticipation*, give $\begin{smallmatrix}6\\4\end{smallmatrix}$ on the dominant bass followed by $\begin{smallmatrix}8\\3\end{smallmatrix}$ on the key; at *c*, where the resolution of the sensible note produces $\begin{smallmatrix}7\\4\end{smallmatrix}$ on the dominant bass, the resolution of the rest of the chord taking place regularly; or at *d*, where the anticipation of the tonic bass gives to it the chord of $\begin{smallmatrix}7\\4\\2\end{smallmatrix}$, followed by $\begin{smallmatrix}8\\5\\3\end{smallmatrix}$.

Discords of anticipation are prepared on the accented part of the measure, struck on the unaccented, and resolved on the accented. It is unnecessary to enter into so particular an examination of these as we have done of chords of suspension.

Suspensions and anticipations are sometimes intermixed, on which subject we shall be contented with quoting a short paragraph from Mr. Kollmann, with his examples.

"The suspensions and interruptions may be intermixed, either so that they succeed one another in the *same part* of the harmony; or in different parts at the same time and at different times. This creates a great number of accidental combinations, to which I endeavour to show the way in the following examples. At No. 2, see a series of essential chords. At No. 3, see the same harmony, but suspensions in the first part, and interruptions in the third part from above. At No. 4, see the interruptions in the first, and the suspension in the third part."





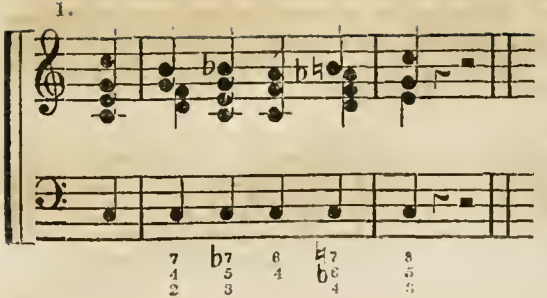
202. To the class of suspensions or anticipations, may be referred what are called *pedal harmonics*, or *organ points.* An organ point consists of several harmonies taken over a continued bass note, which note is foreign to some of the harmonies, and forms with them the same or similar combinations with those which we have seen arising from suspensions. One example we have already given, Art. 199, No. 1, *g*, where the chord of the thirteenth, that is, the chord of minor seventh with minor fifth on the sensible note, is taken over the key-note, and the chord of the eleventh, or dominant chord of seventh over the key-note, both occur. This is called a *tonic* pedal, or organ point. Other harmonies are frequently taken in succession, such as that of the fourth of the key, or its dominant, or the diminished seventh on the sensible note, even when the key is major. These all occur in No. 1, which is taken from a figured bass of Emanuel Bach, given by Mr. Shield in his Introduction. The bass note belongs to all the chords except the second and fifth chords. The next example, No. 2, is also taken from Mr. Shield, whose excellent observations we copy. "It is rather extraordinary, that the most fertile composers have uniformly preferred the following progression to the charms of novelty in their regular crescendos; for although it must be acknowledged, that the effect of such passages is generally pleasing when they are gradually increased from piano to forte by a multifarious band, yet others might be sought for and found by men of genius."

When similar harmonies are taken on the fifth of the key as holding-note, the passage is called a *dominant* organ point. No. 3 contains a short tonic organ point, and a dominant pedal point, which, for the great variety of modulations taken over that holding note, is worthy of the student's careful consideration. After the tonic pedal in the five first measures, there is the appearance of a formal conclusion in the key, which however is prevented by the key-note being made 7th in the dominant leading to the fifth of the key at *A*. Here commences the pedal or organ point on the dominant note. First, this dominant has its chord of minor 7th, resolving on $^{6}_{4}$. At *B*, we have the chord of redundant sixth leading to E, second of the key, as the dominant of the dominant; or, if you please, as the bass belongs to the chord of redundant sixth, it is the first inversion of that chord, major 4th, and minor 6th. At *C* we have E, the second of the key as dominant chord, leading to A the fifth of the primary key, producing over the bass the chord of eleventh. At *D*, this chord resolves on the fifth with dominant 7th and minor 9, which last resolves on the $^{6}_{4}$. At *E* we have the second inversion of the diminished 7th leading to E, the bass belonging to the chord. At *F* we have the dominant to our bass resolving at *G* as before into the $^{\flat 9}_{\natural 7}$. At *H*, we have the chord of thirteenth or diminished 7th, taken over the bass; which at *I* resolves on the fourth and major sixth, the minor sixth to the bass (which is the diminished 7th of the chord) rising chromatically. This example is from the minuet in Haydn's celebrated symphony in D.

In the above given examples, all the chords over the bass holding-note take their natural progressions without any suspensions. No. 4, as a dominant organ point in the key of C minor, in which, besides the holding bass note, there are suspensions in the upper parts. The holding bass note belongs to all the chords, except the chord of thirteenth or diminished seventh, leading to the dominant, at the end of the third measure: and the eleventh and thirteenth being suspended in the two highest parts, while the 4th is resolved on the major third, next the bass, makes a combination of major third, perfect fifth, eleventh, and thirteenth minor, retarding the fifth and seventh of the dominant chord. At the resolution into the key, the major third and fifth proceed to the tonic harmony next the bass, while the fifth and seventh of the dominant are suspended, making a chord of minor third, perfect fourth, and ninth, retarding the third and octave. This example is taken from an instrumental quintetto of Mozart.

Sometimes a holding note is set in the upper parts, while it is foreign to some of the chords in the harmony, as in No 5, where E fifth of the key is held on, and in the beginning of the third bar makes to F♯, the relative minor, a seventh, which is not resolved, but continues as minor sixth to the sensible note. This may be considered as an inverted dominant pedal.

1.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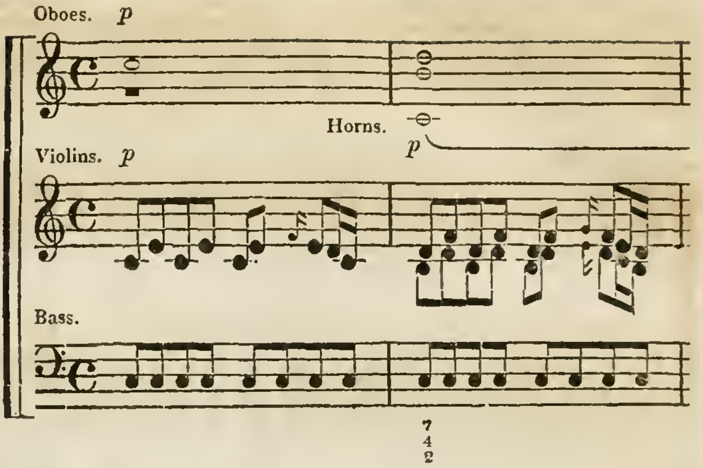
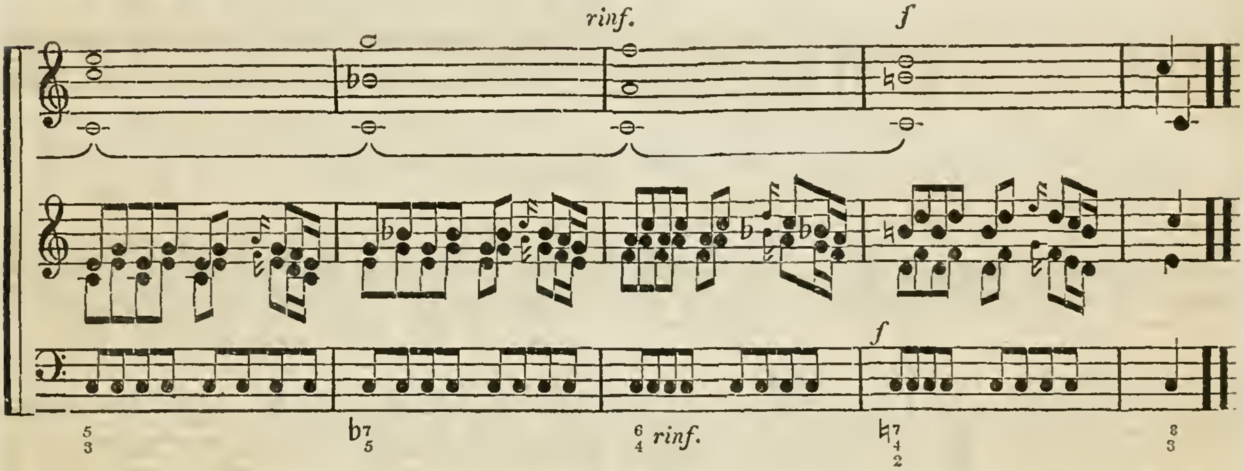
6 4
♮7 ♭6 4 2
8 5 3

2.


Oboes. p
Horns.
p
Violins. p
Bass.
7 4 2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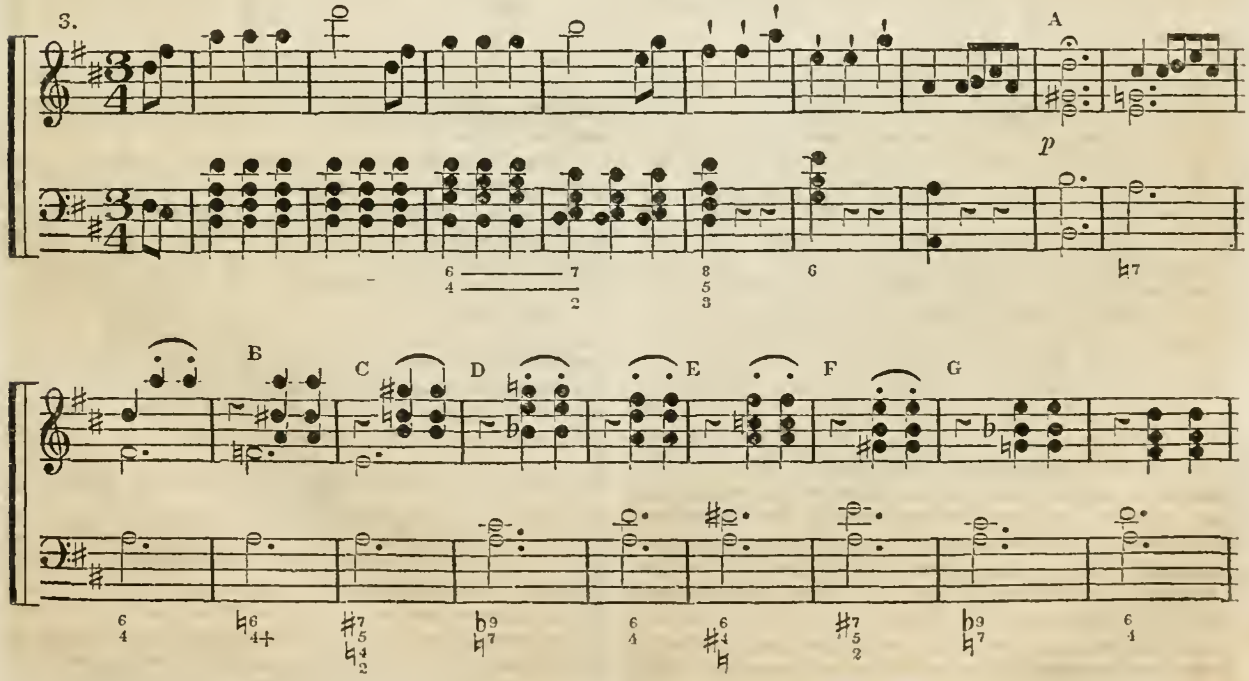
3.


A
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6 4 7 2
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6
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B
C
D
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G
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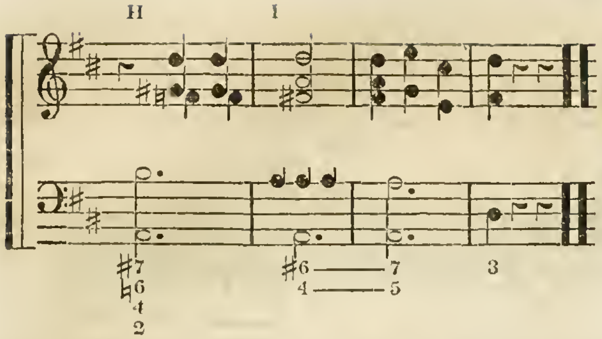

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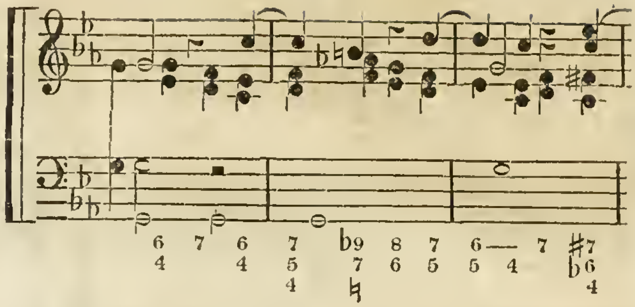

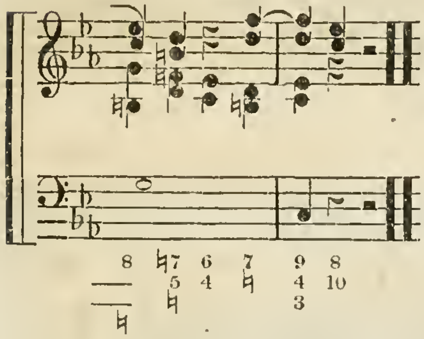

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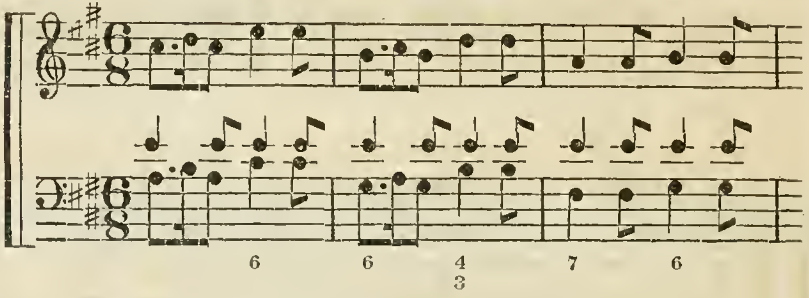

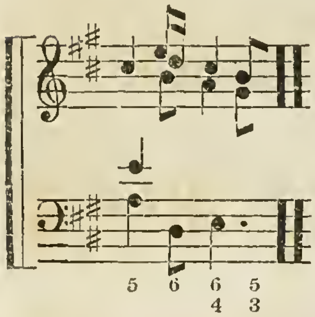

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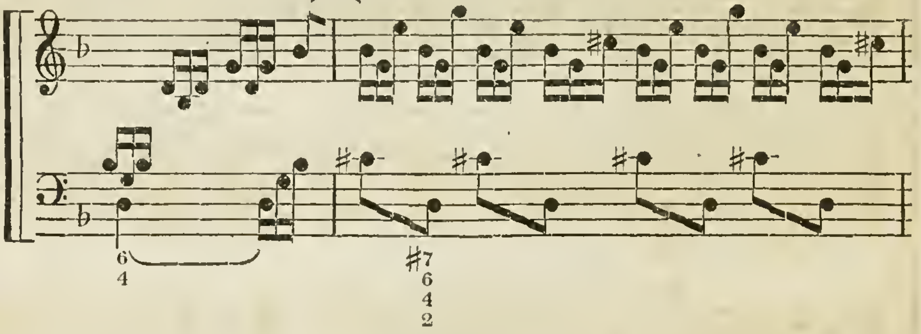
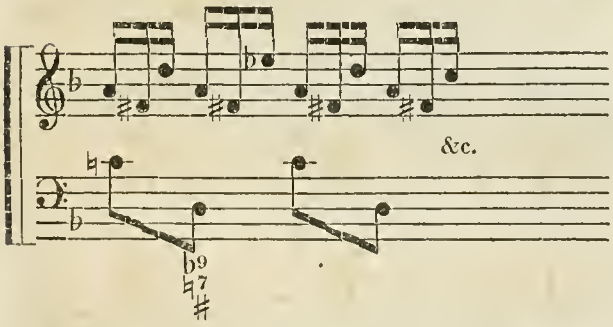




No. 6 is an organ point in the bass, though at first sight it has not that appearance from the motion of the bass. The continual repetition of the D has the effect of making it a holding note. It is foreign to the chord of the second bar; but it is the proper fundamental bass of the third. We regret that the whole passage is too long for quotation, as it is well worthy the reader's study. It is from the prelude to Sebastian Bach's fugue in D minor.

203. Discords are introduced freely by diatonic degrees, ascending or descending, and are all called *transient* or *passing* notes, and by the French, notes of *supposition*. We cannot explain this more shortly, or more clearly, than in the words of Rousseau.

"When several notes ascend or descend diatonically in one part, on one continued note in another part, then these diatonic notes cannot all be harmony, or enter at once into the same chord; there are therefore some of them which count for nothing: and these notes, foreign to the harmony, are called notes *by supposition.*

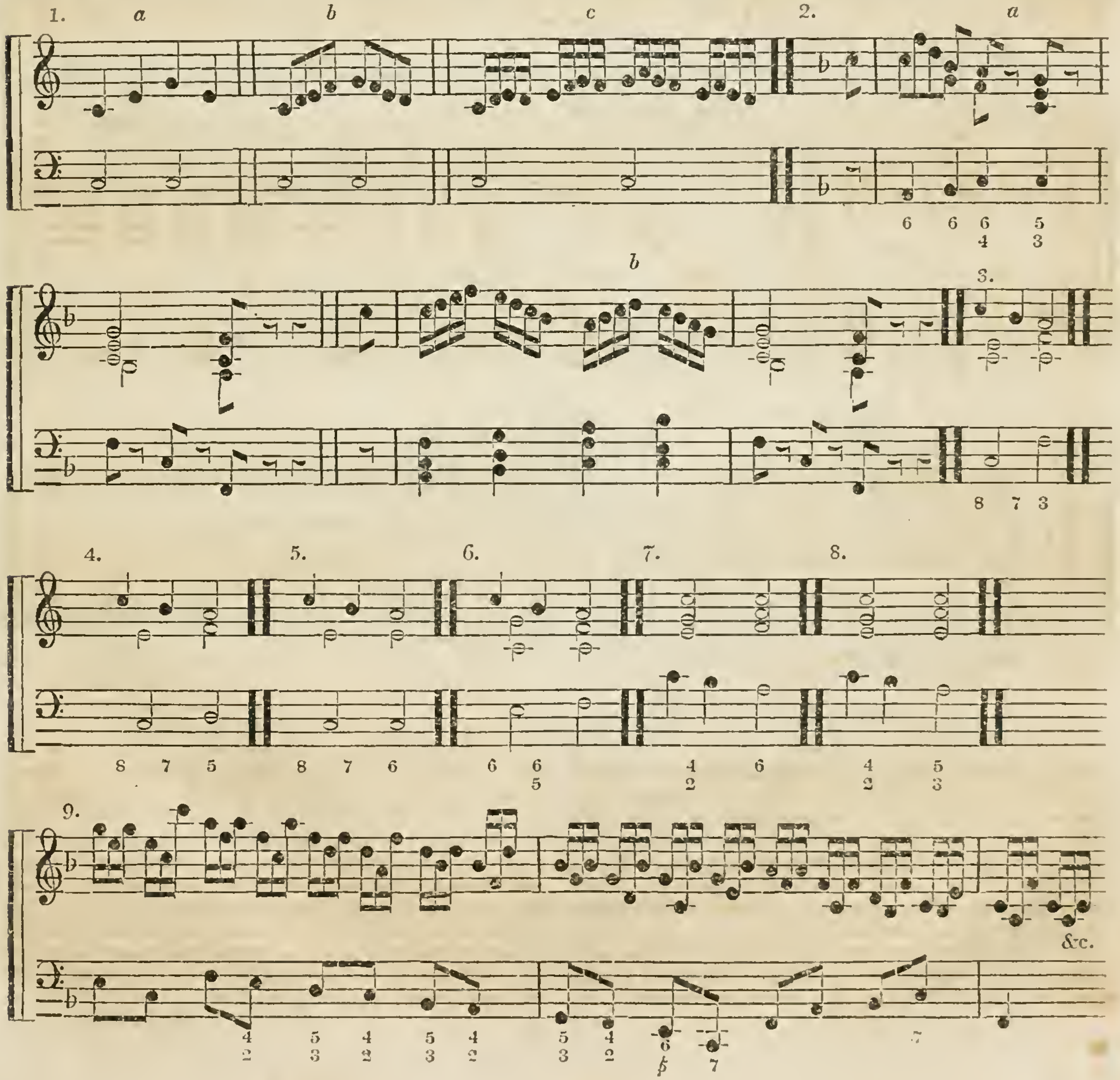
"The general rule is, when the notes are equal, that all those which are struck on the strong (or accented) times, bear harmony: those which press on the weak (or unaccented) times, are notes of *supposition*, which are only introduced for the sake of the melody, and to form conjoint degrees. Observe, that by *strong and weak times*, I understand here, less the principal times of the measure, than the subdivisions of each time. Thus, if there are two equal notes in one time, it is the first which carries harmony; the second is a note of *supposition.* If the time is composed of four equal notes, the first and the third carry harmony, the second and the fourth are notes of *supposition*, &c.

"Sometimes this order is reversed: we pass the first note by supposition, and make the second time bear harmony; but then the value of the second note is generally augmented by a point, at the expense of the first.

"All this supposes always a movement by conjoint diatonic degrees; for when the degrees are disjoined, there is no supposition, and all the notes ought to belong to the chord."

To this we must add, that when between the parts of the chord there is interval of fourth, it is frequently filled up with two passing notes, one of which will be on the accented, and the other on the unaccented part of the Time. One or two examples are sufficient. No. 1, *a*, the notes are the common chord of C, varied with passing notes at *b* and *c*, on the weak parts of the times. No. 2, *a*, is a cadence in the key of F. At *b*, the same, varied with transient notes; the interval of fourth, from C to F, in the first chord, is filled up with two passing notes: in the second chord the passing notes are on the strong parts, viz. the 1st and 3d of the time: in the third chord, $\begin{smallmatrix}6\\4\end{smallmatrix}$ to C, the transient notes are again regular, and in the last chord, that of dominant 7th to C, there is only one passing note, viz. A, the rest belonging to the chord; but the octave is used as an appoggiatura to the 7th. When the transient notes appear on the strong parts of the time, or measure, Mr. Kollmann calls them *unprepared suspensions*. We shall call them unprepared Appoggiaturas.

These passing notes between the parts of a chord are not noticed in the figuring of thorough bass. But when the passing note occupies a whole principal time of the measure, in going from one chord to another, they are frequently figured. By the diatonic progression, the necessity of preparation is superseded, and discords are gradually brought in, which, according to the general rules, ought to be prepared. Thus No. 3, the major 7th, is taken after the octave, and regularly resolved as a chord of seventh. In No. 4, the same chord, similarly brought in, is resolved by the diatonic rise of the bass on the minor chord of the second of the key. No. 5 is the same 7th resolving on the chord of sixth to the bass. The first of these progressions, No. 3, is frequently inverted in the unprepared fifth, made a discord by the sixth, as No. 6; or by an unprepared second in the bass, as No. 7. This unprepared second is frequently resolved on the common chord, as No. 8; which is an inversion of that in No. 5. No. 9 is a passage in which Bach, by repeating this progression, conducts the modulation from the key successively to the common chords of the sixth, the fourth, and the second, and thence, by resolving the chord of unprepared 2d, as in No. 7, on the first inversion of the dominant, makes a close on



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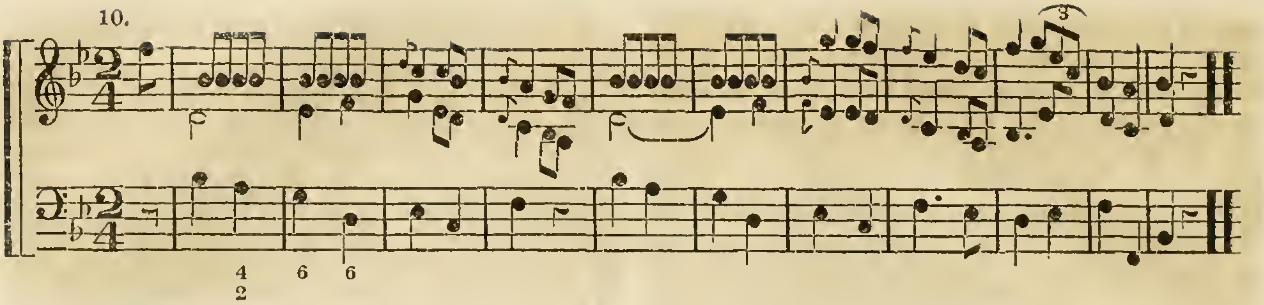

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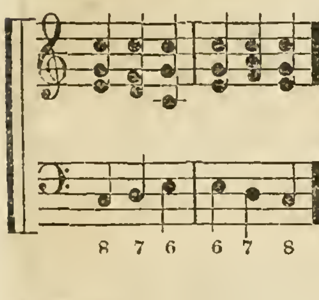

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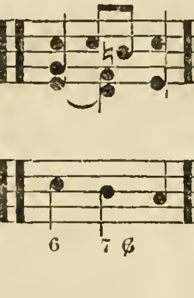

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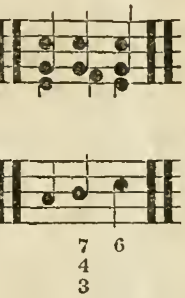

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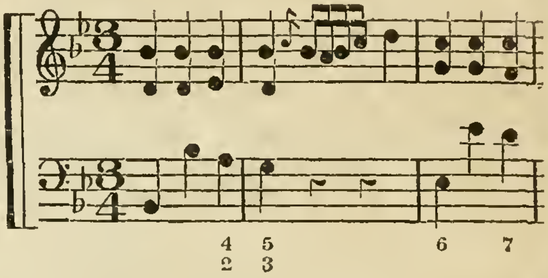
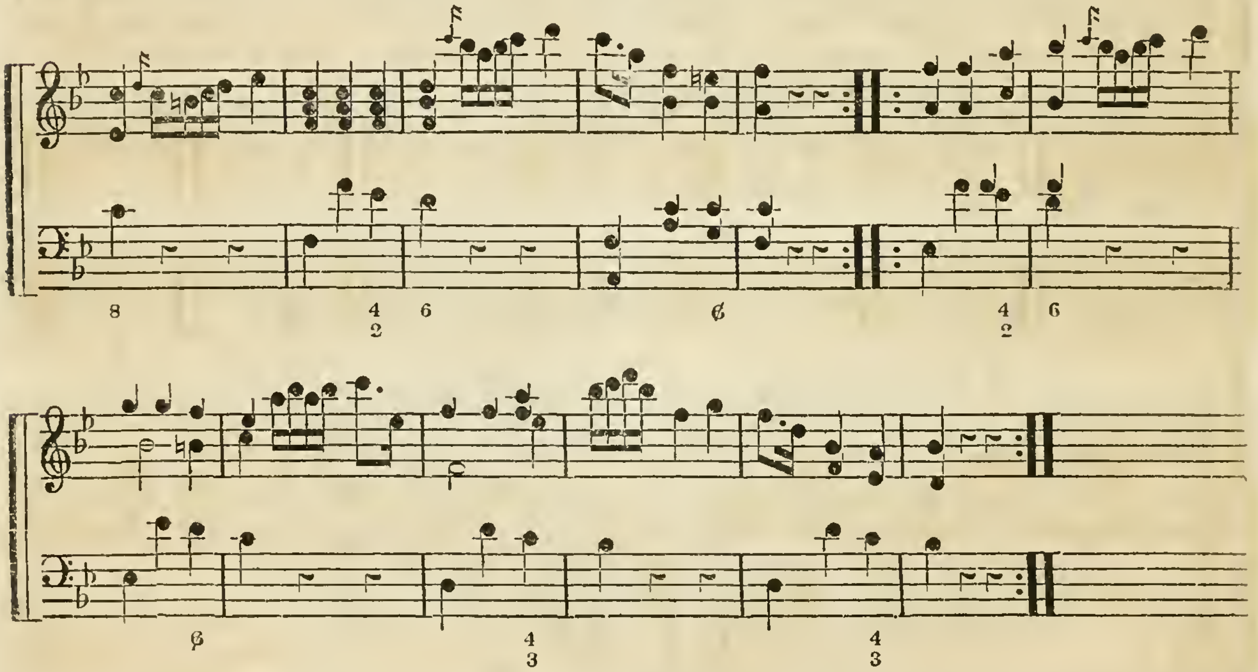




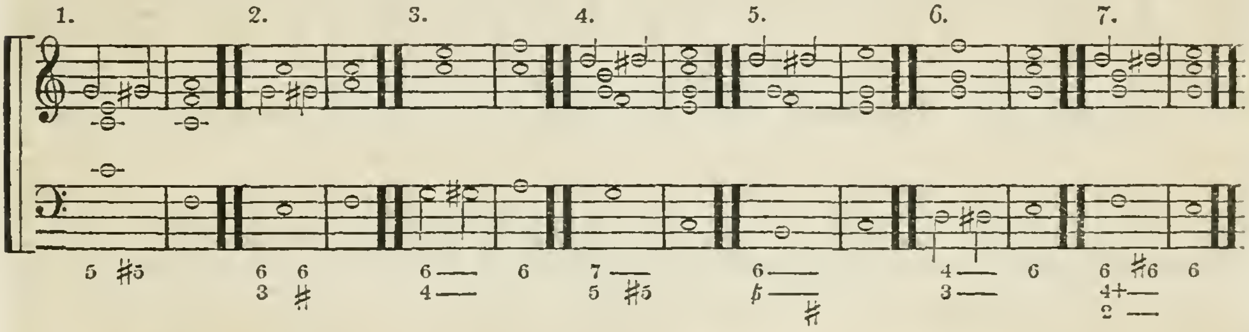
the key. In No. 10, Mozart takes the unprepared $\frac{4}{2}$ on the unaccented part of the first measure, and resolves it on the chord of sixth, as No. 7. The major seventh, in the beginning of the third measure, is an unprepared appoggiatura, and is a grace not to be considered in the harmony. We quote the whole period, in order to avoid repetition, as we shall have again occasion to refer to it on the subject of rhythm.

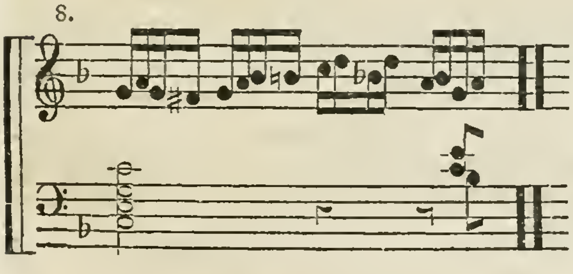
Discords, introduced by passing notes, are frequently not resolved according to the analogy of the chords, and become perplexing to those who are beginning the study of harmony. Thus, in No. 11, the seventh in the second chord of each measure is not resolved at all. It may be explained as a transient note, in the bass; or the 7th may be considered as a holding or pedal note; or it may be taken as *elliptical* for No. 12, the resolution being omitted. In No. 13, by two passing notes in the bass and part next it, we have the chord of $\begin{smallmatrix}7\\4\\3\end{smallmatrix}$ as a transient chord. No. 14 is an elegant minuet in one of Haydn's symphonies, in which those passing discords occur. In the end of the first measure, the unprepared second and fourth brings us to the chord of the relative minor, as in No. 8. At the end of the third measure we have the 7th on the third of the key, passing to the minor common chord on the second of the key: in the corresponding measure of the second strain, the same progression in the bass makes a real inverted cadence on the second of the key, which may illustrate the explanation of the former as *elliptical.* In the fifth measure of the first strain, and in the first measure of the second strain, we have the $\frac{4}{2}$ third inversion of the dominant brought in after the same manner, but resolved regularly on the first inversion of the key. The uniform progression of the bass contributes greatly to the elegant simplicity of the effect, while the variety of the harmony prevents any thing like monotony.

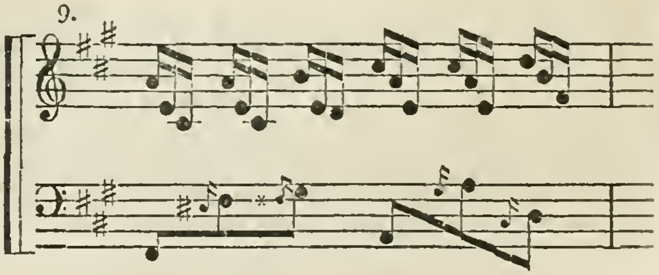
204. The last head, under which we classed discords, in Chap. III, was those produced by the chromatic alterations of the intervals. Major intervals, by being chromatically enlarged, become redundant; and minor intervals, by being chromatically lessened, become diminished intervals. We have already treated so fully of the redundant second and diminished seventh, of the diminished third and redundant sixth, that we have no occasion to recur to these under this head. We have also seen a specimen or two of the redundant fifth, as arising from suspension. In No. 1, this interval is introduced by the chromatic ascent of the fifth of the chord. This example is from Monsieur Choron, who also gives the inversions of the passage in Nos. 2 and 3. The combination of major third and lesser sixth, as in No. 2, Dr. Burney observes, was exceedingly frequent about the end of the 17th and beginning of the 18th century; and he very justly calls it a *hateful* combination. The dominant chord, M. Choron observes, is susceptible of the same modification of the fifth, of which he gives the examples in Nos. 4, 5, 6, and 7.

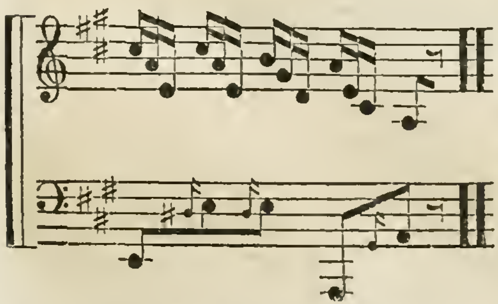
Modern composers, in their instrumental pieces, introduce transient chromatics with great freedom, and frequently so as to produce combinations altogether unaccountable as harmony. They either divide the interval of tone into semitones, or are substituted in place of the proper notes of the scale, for the sake of the melody; as in No. 8, where the F𝄪 is taken instead of F♮, and the B♮ divides the tone between the B♭ and C. Both these notes are foreign to the common chord of C. The *Acciaccatura* is a passing chromatic, the semitone below the note being struck almost at the same time with the note itself, and quitted immediately, as if it were red hot, says Dr. Burney. No. 9.

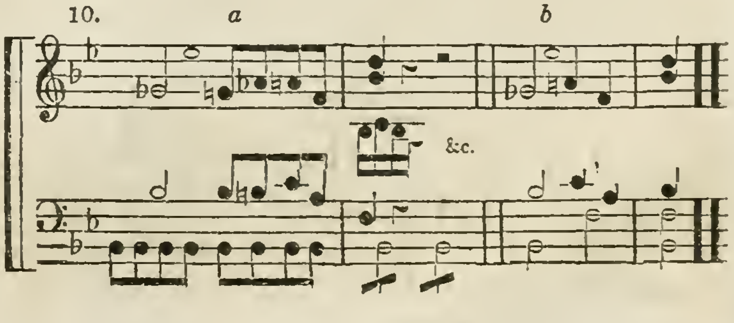
Such passing chromatics are not difficult to understand; but when they are taken over a *pedal* bass, they produce combinations very puzzling to the student who endeavours to unravel them. No. 10, *a*, is such a passage, from a quintetto of Mozart. The progression of the harmony is shown at *b*, stript of the passing notes, and of the pedal bass. In the second violin the redundant second, from G♭ to A♮, is divided into semitones by G♮ and A♭; and at the same time the tenor divides the tone from B♭ to C by B♮, which produces on the holding bass B♭ a redundant octave and minor sixth. These passing notes are not to be regarded as belonging to the harmony; they are introduced for the sake of the melody of the particular part where they appear. The use of them is to be directed by *taste* rather than rule; and this taste is only to be acquired and cultivated by listening often and attentively to the works of the best masters.











CHAP. XI.

OF RHYTHM, CADENCES, MODULATION, SUBJECT.

205. We are now to explain more particularly the distinguishing characteristics of Air, mentioned in Art. 179, viz. Rhythm; regularly disposed Cadences; Modulation, belonging to a principal key, or passing into other keys more or less related to the principal one; and lastly, Subject; which last is of such importance, that, according to the observation of Zarlino, without it there can be no composition. *In ogni buon contrappunto, ovvero in ogni altra composizione, si ricercano molte cose—la prima è il soggetto, senza il quale si farrebbe nulla.* (*Zarlino, Istit. Armon.* p. 3. cap. 26.

206. The rhythm of modern compositions, we have already observed, (Art. 180,) is constituted of equal measures; and we have, in the subsequent articles of the ninth chapter, fully explained and exemplified the different species of measure. But it would not be sufficient to give the character of rhythm to a composition, that it were divisible into equal-timed measures. An indefinite series of measures, no way distinguished from each other, would be mere *prose*. Several measures must be grouped together, by means of the phrases of the melody and cadences in the harmony forming distinct portions, several of which, properly united, form the Air. These subdivisions of air are so plainly analogous to verses in poetry, and indeed the prosody of music is so truly the same doctrine with that of poetry, that we shall adopt the terms of the latter as equally applicable to that of which we are treating. The constituent parts of rhythm, therefore, we define as follows:

A *Foot* is the quantity of one measure. If the subject were always to begin on the first note of the measure, the foot and the measure would coincide, and there would be no occasion to distinguish them. But as the bars are placed in such a way as to mark the places of the principal accents, and as the subject very often begins on the unaccented part of the measure, the distinction is of importance.

From this definition of the musical Foot, it is plain that there are as many kinds of feet as there are of measures.

Two or more Feet constitute a *Verse*. Hence it is plain that there is still greater variety in the kind of verses, than in those of measures or feet.

Two or more verses constitute a *Strain* or *Stanza*. We would, however, make a distinction in the use of these two words. The word strain we would apply to what are usually called the first and second parts of national tunes, or airs formed on that model. The word stanza we would use to denote those portions into which longer pieces of music, such as sonatas, concertos, symphonies, &c. are divided by formal closes, yet not marked by double bars. The distinction perhaps is not of great importance, but it cannot occasion any perplexity or confusion.

207. These constituent parts of rhythm will be best exemplified by being exhibited, not separately, but united in the whole of which they are portions.

The air No. 1, consists of two strains. Each strain is by the phrases of the melody, as well as by the cadences in the harmony, divided into four portions of two feet each, which we have marked thus, (1), ($\overset{*}{2}$), (3), ($\overset{*}{4}$), which we call verses of two feet, or *dimeters*. If the student attend to his own feelings in performing or listening to this air, he will find that the conclusion of the verses marked ($\overset{*}{2}$) and ($\overset{*}{4}$), is more remarkable and striking than those at (1) and (3); insomuch that each pair of verses is a kind of whole, and might very well be considered as one verse. It is for this reason that we have marked them with asterisms: and we may consider the strain as consisting either of four dimeters, or of two verses of four feet each, which we may call *tetrameters*. In our subsequent examples we shall have occasion to notice both dimeters not thus united in pairs, and tetrameters not distinctly divided in two, either by the turn of the melody, or a cadence in the harmony. Hence the propriety of our noticing both kinds of verse.

The example No. 1, is in common time of two principal times in the measure, where each foot includes one principal accent. Our next example, No. 2, is in common time of four principal times in the measure. It is plain that the portions of melody marked (1), ($\overset{*}{2}$), (3), ($\overset{*}{4}$), bear exactly the same relation to this air that the portions similarly marked do to the air No. 1. But the feet are compound or double, including two principal accents. Here, then, we have dimeters, and, if you please to take the first and second pairs as making one verse each, tetrameters of a different kind from the former. And this shows the reality of the distinction between these two kinds of common-time measures. If any one should be disposed to contend that these double measures, or feet, may be divided into simple ones, by inserting a bar in the middle of each, we shall not dispute it: but we must still maintain the difference in the kinds of rhythm. The constituent verses of the strain would still be the four marked in the example; and the only difference would be in the number of feet assigned to each. It is of little importance in itself whether we call each of these verses a dimeter of double feet, or a tetrameter of simple feet; just as the Greeks called the same verse an iambic dimeter, which the Latins called a quaternary. But the practice of musicians establishes these double or compound feet. We, however, find in the older masters this double measure used, where the simple measure would be more appropriate, as in No. 3. Here each verse consists only of one double foot. This is plainly the same kind of rhythm with No. 1, and might be better written in $\frac{2}{4}$ as that example. (In this example Handel sets only two flats at the clef, in the key of C minor, and marks the A♭ as it occurs, as an accidental.)

On the other hand, we sometimes find the same kind of rhythm with No. 2, written in $\frac{2}{4}$ measures; so that the verses are tetrameters, as in No. 4.

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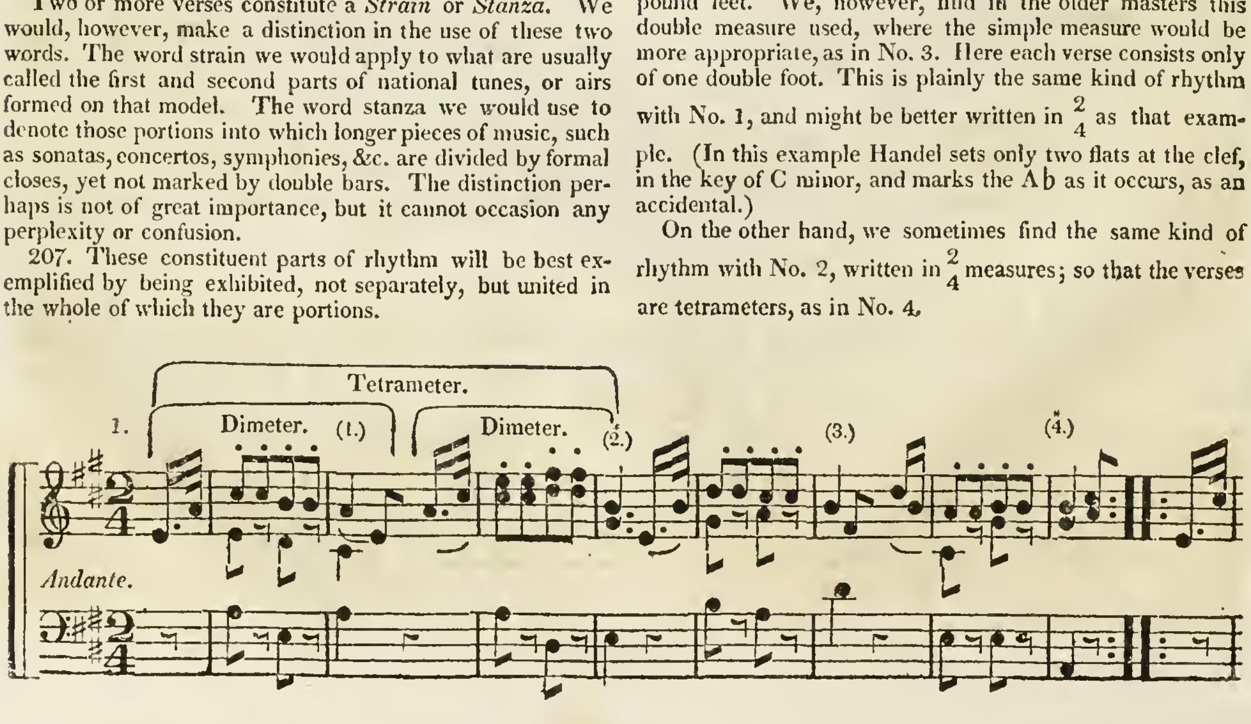
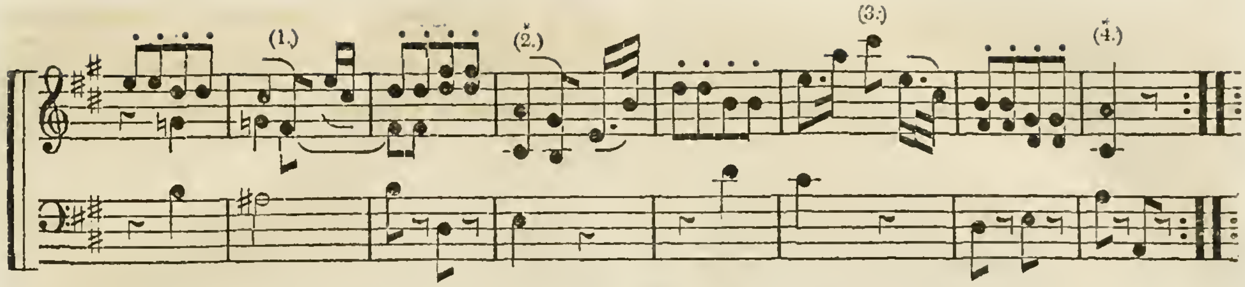
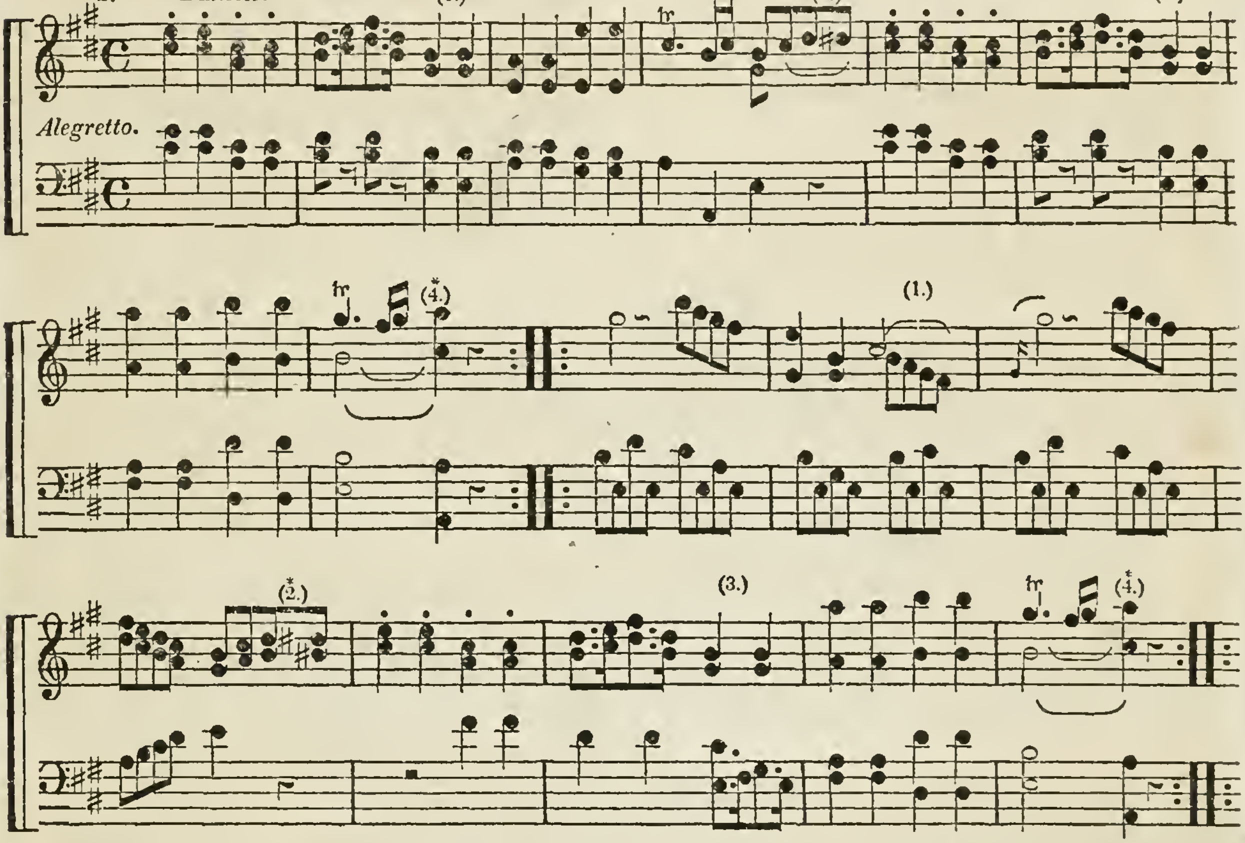




2. Dimeter.



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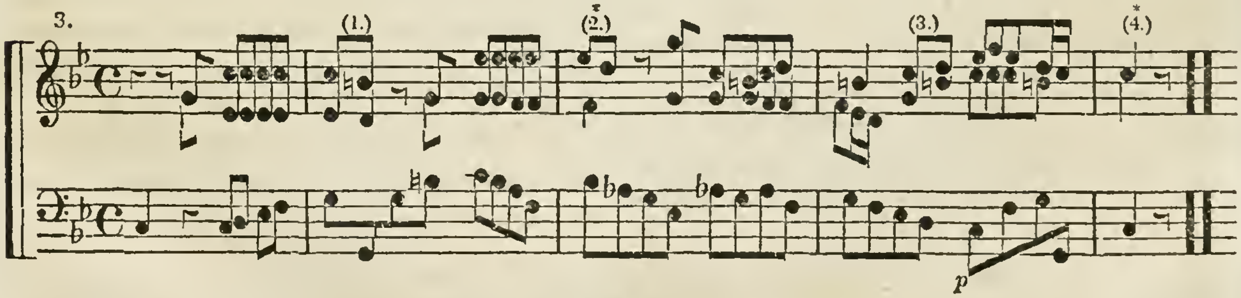
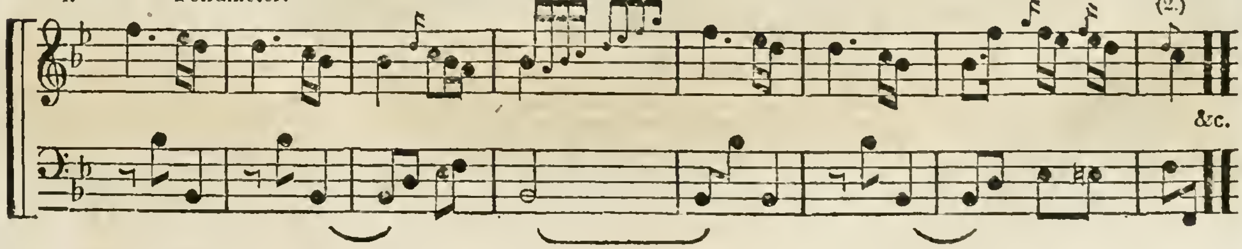


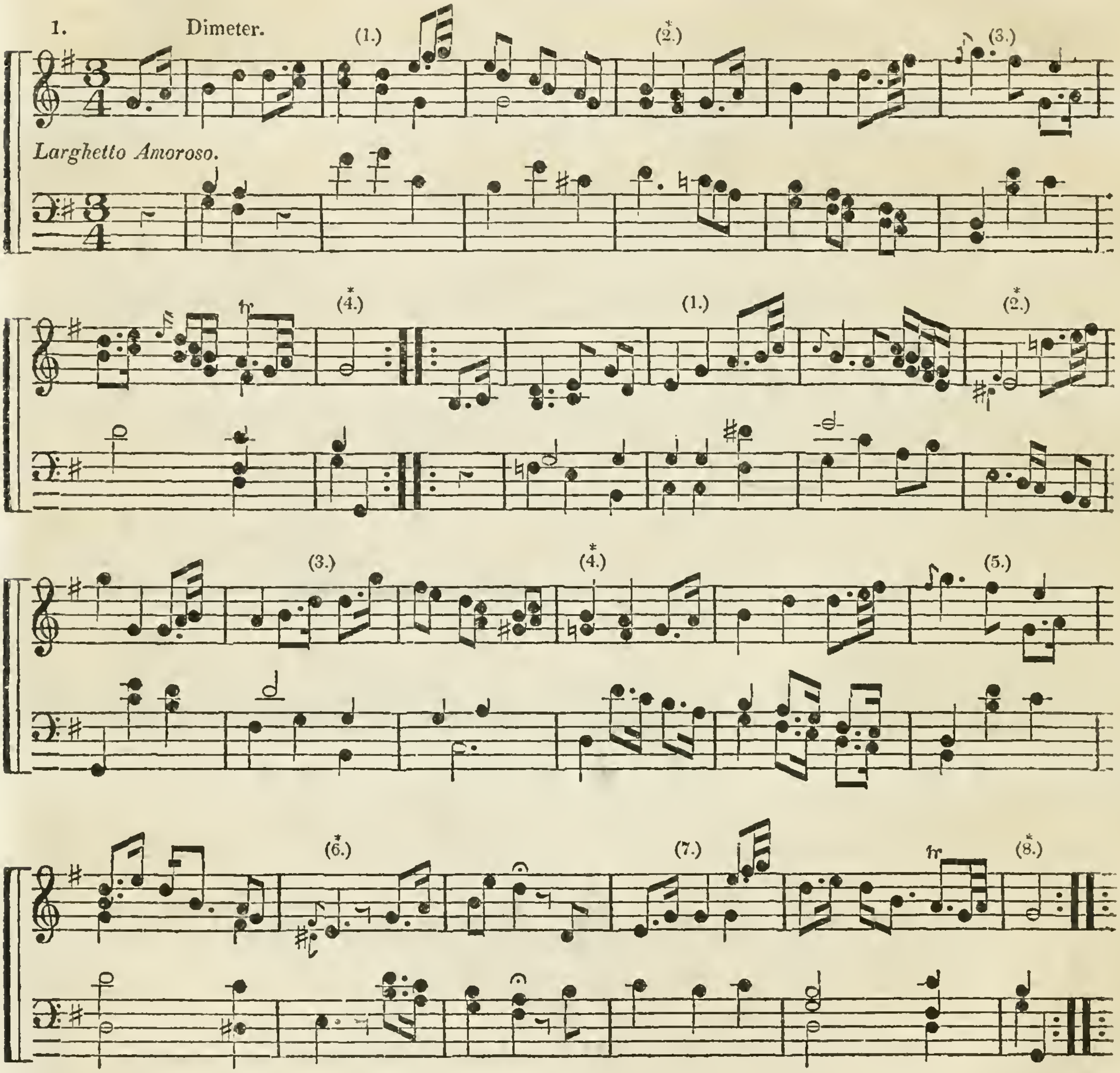
4. Tetrameter.



208. After the same manner, in triple time, we have dimeters, or tetrameters. In No. 1, the first strain consists of four dimeters, the 2d and 4th being still the emphatic or chief conclusions: The second strain consists of eight verses, those marked with the even numbers being still the most important. The seventh verse is by the pause divided distinctly into two feet.

So in double measure of triple time, as in No. 2, this example, if considered as one strain, consists of seven verses of two feet, in consequence of the broken cadence at the sixth verse, which occasions a seventh verse, in order to come to a full conclusion. And this is one means of breaking the formality and uniformity of an even number of verses in the strain.

1.



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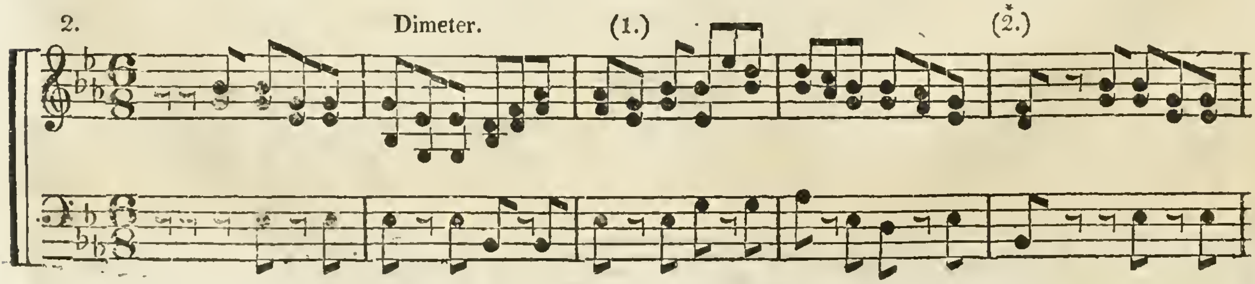
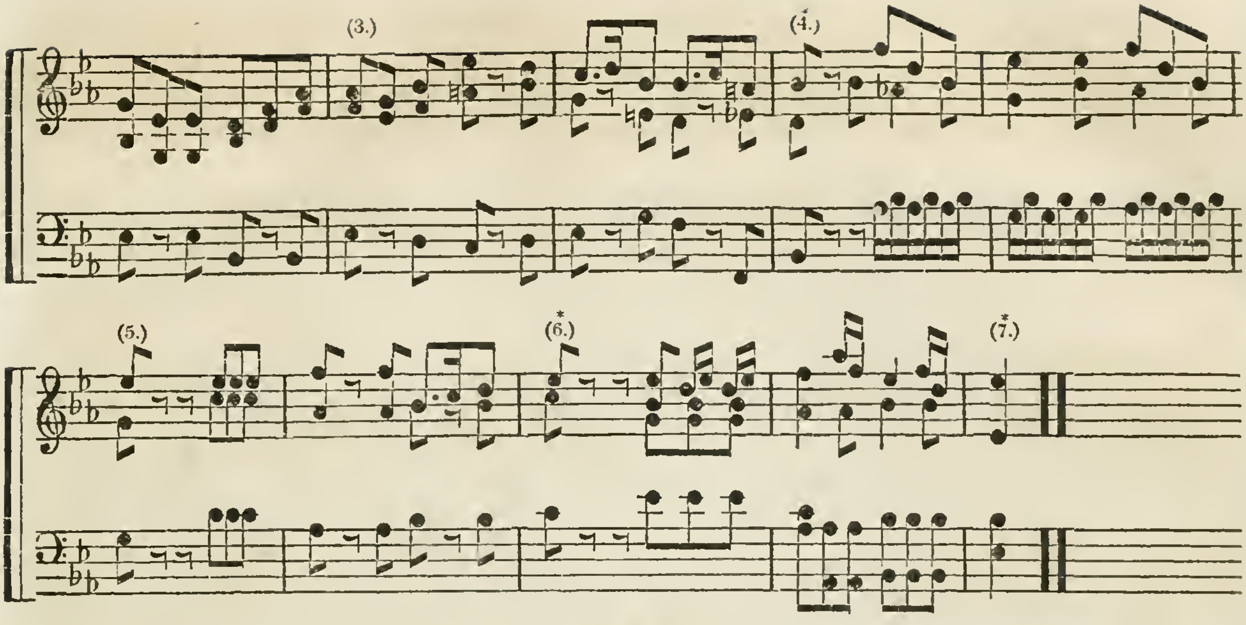


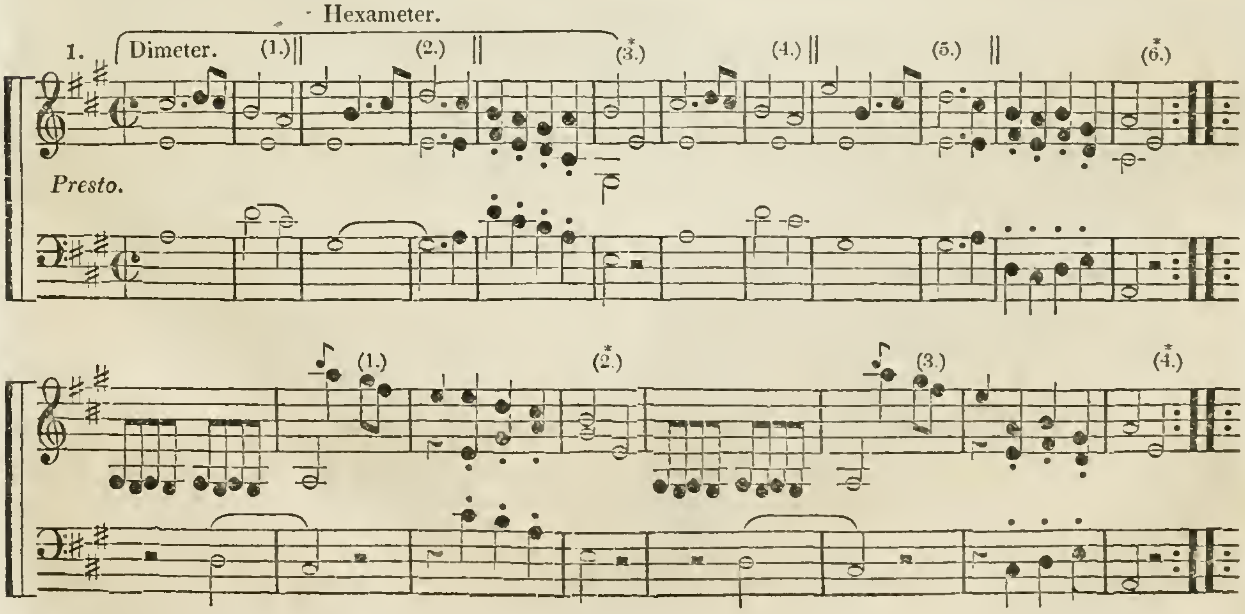


209. As one very desirable object in music is variety, men of genius contrive to attain this object in their rhythm, even in the arrangement of verses of the same length, which at first sight might seem an impossibility. This is attained by variously uniting them in the strain, or its subdivisions. In the preceding examples they are united in pairs, which, as we have observed, form tetrameters; and this is by far the most usual form of musical strains; insomuch that some writers call the phrases of melody so arranged, regular, and all other phrases irregular. In No. 1, the first strain consists of six verses; which are not united in pairs of dimeters, (that is, in tetrameters,) but in two portions of three dimeters each; which we may call *hexameters;* as pointed out by the asterisms over the third and sixth verses. If the second and fifth verses were left out, (as shown by the double strokes separating them,) the strain would be of regular tetrameters, as in our former examples, and as in the second strain of this same air.

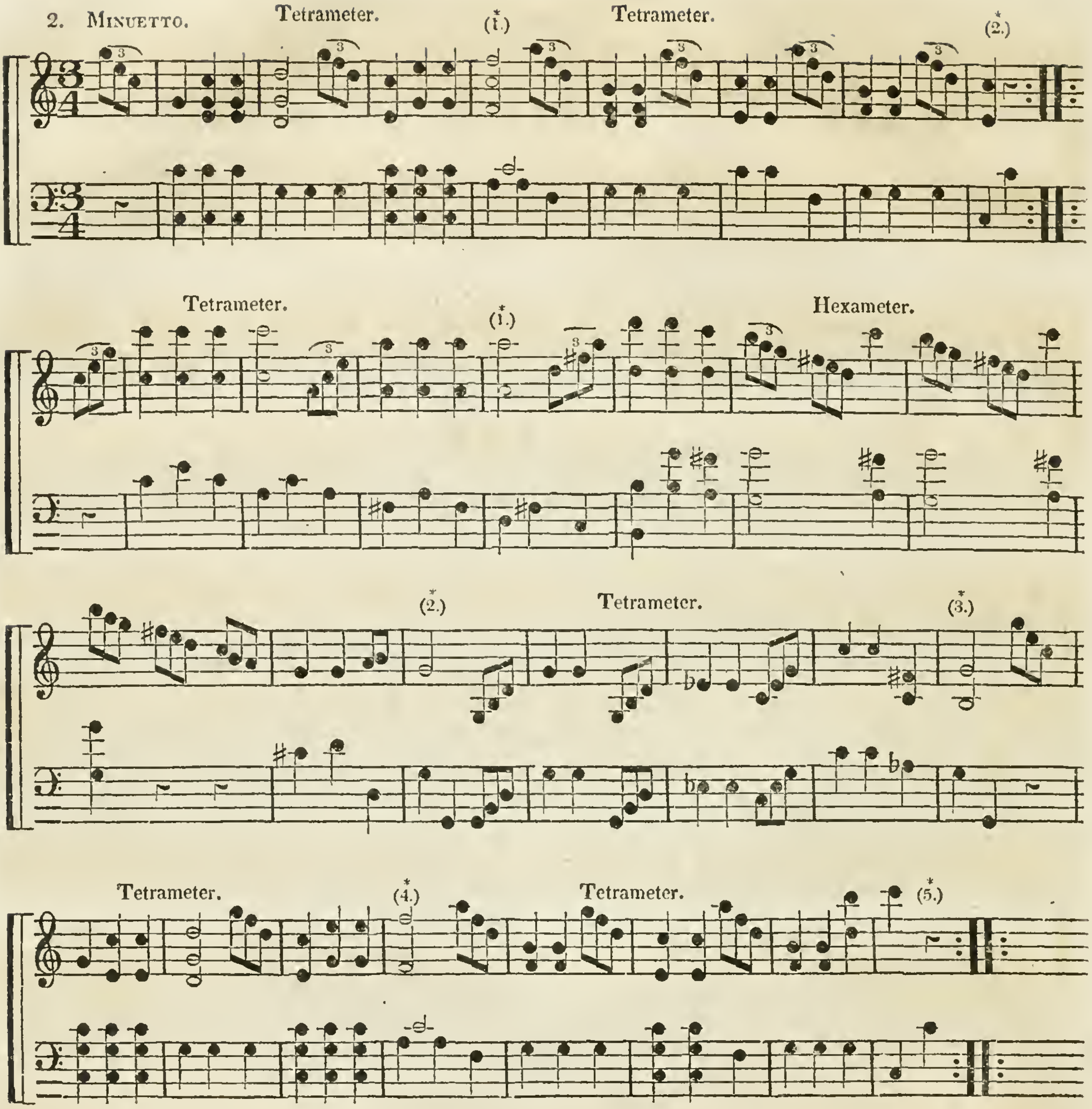
A similar example in triple time may be seen in the first strain of the minuet, Art. 216, where we have put it, that we might not separate it from the second strain, which furnishes examples of rhythm of a different kind.

In the next example, No. 2, we have marked not the single but the compound verses, which are all tetrameters, except the second verse of the second strain, which is an hexameter. The tetrameters are distinctly divided by the air into their constituent dimeters; but the constituent parts of the hexameter verse so run into each other, that it is hardly subdivided, except into feet, which are all marked with equal distinctness, both in the melody and in the harmony.

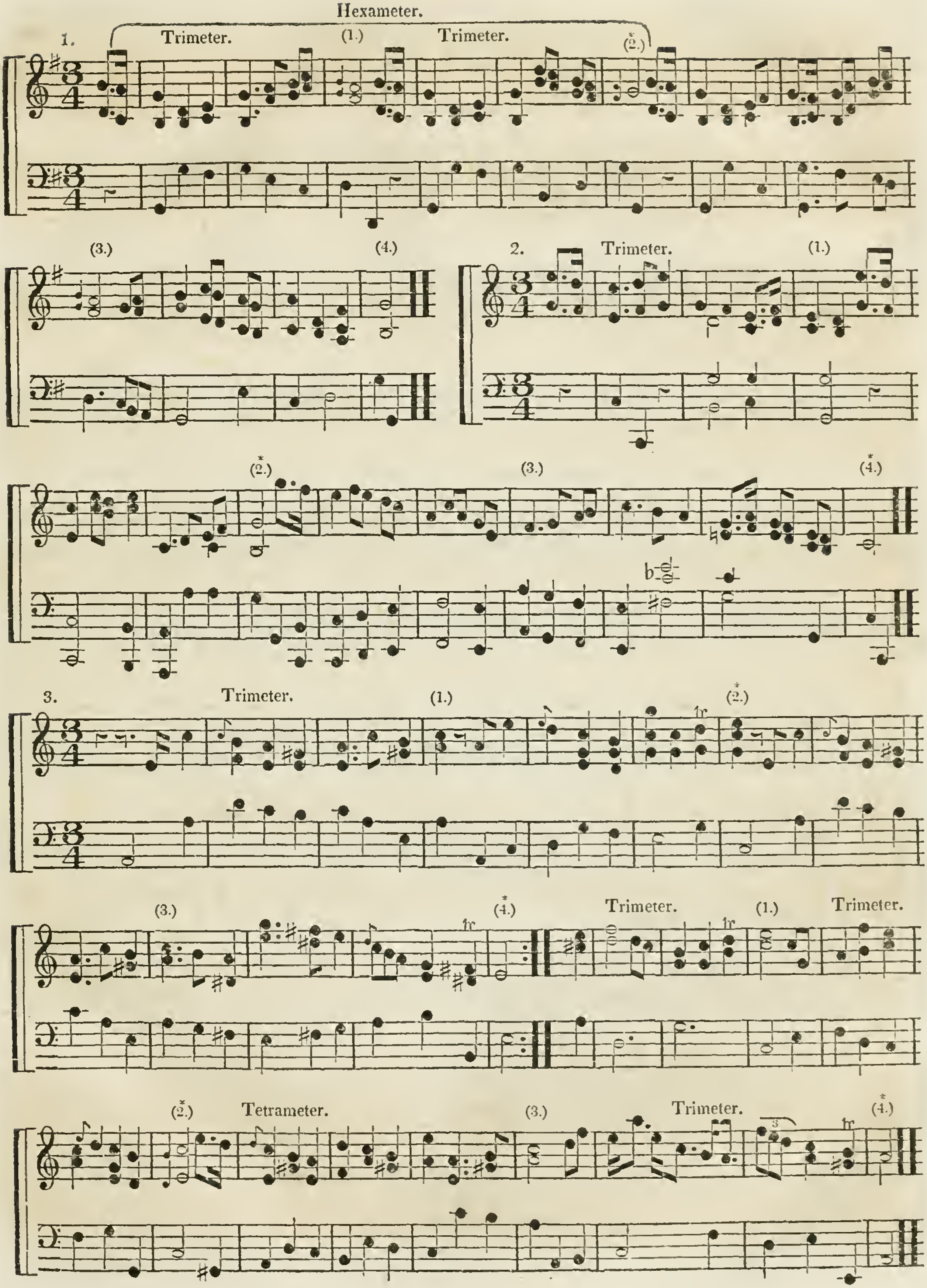
1.



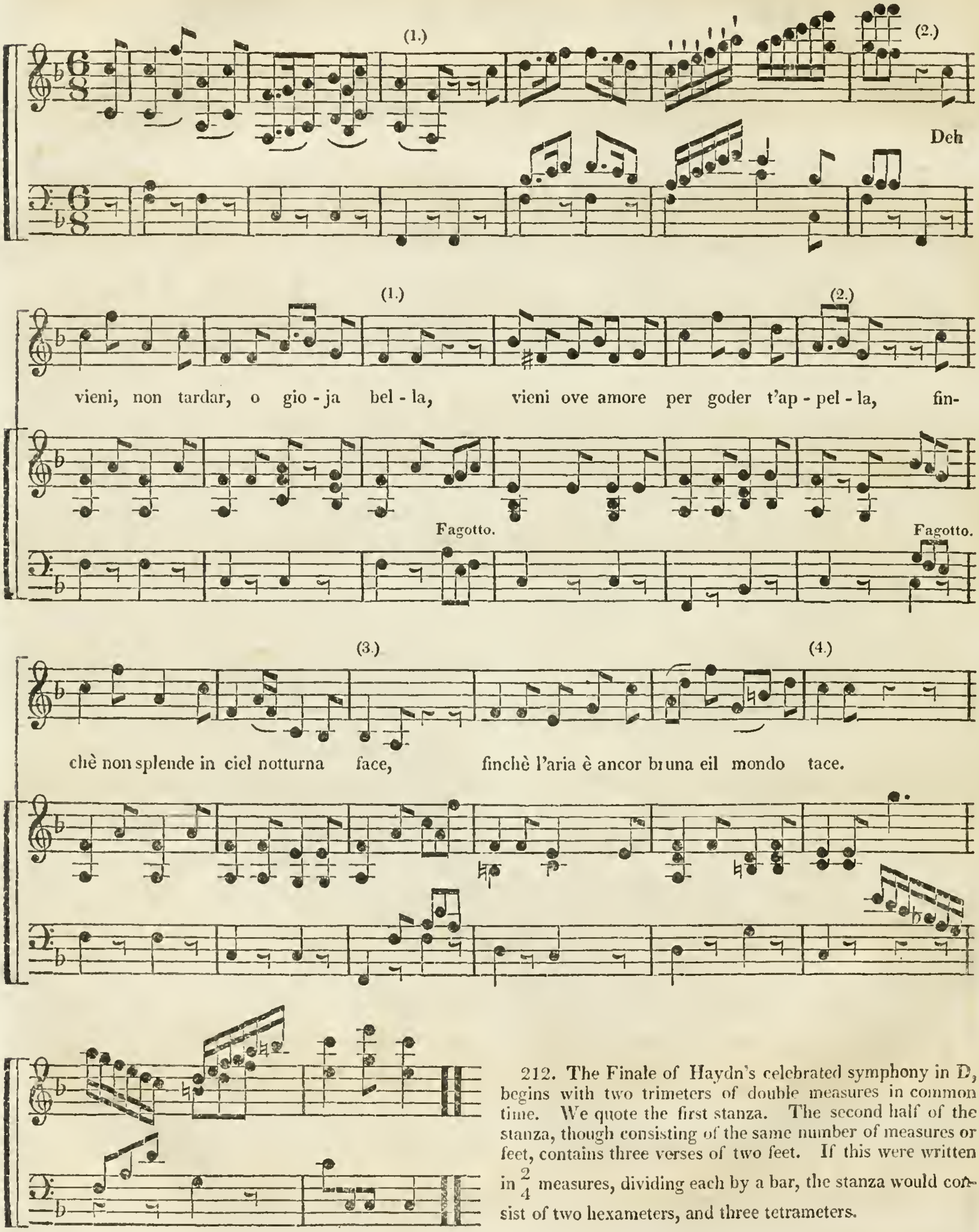
2. MINUETTO.



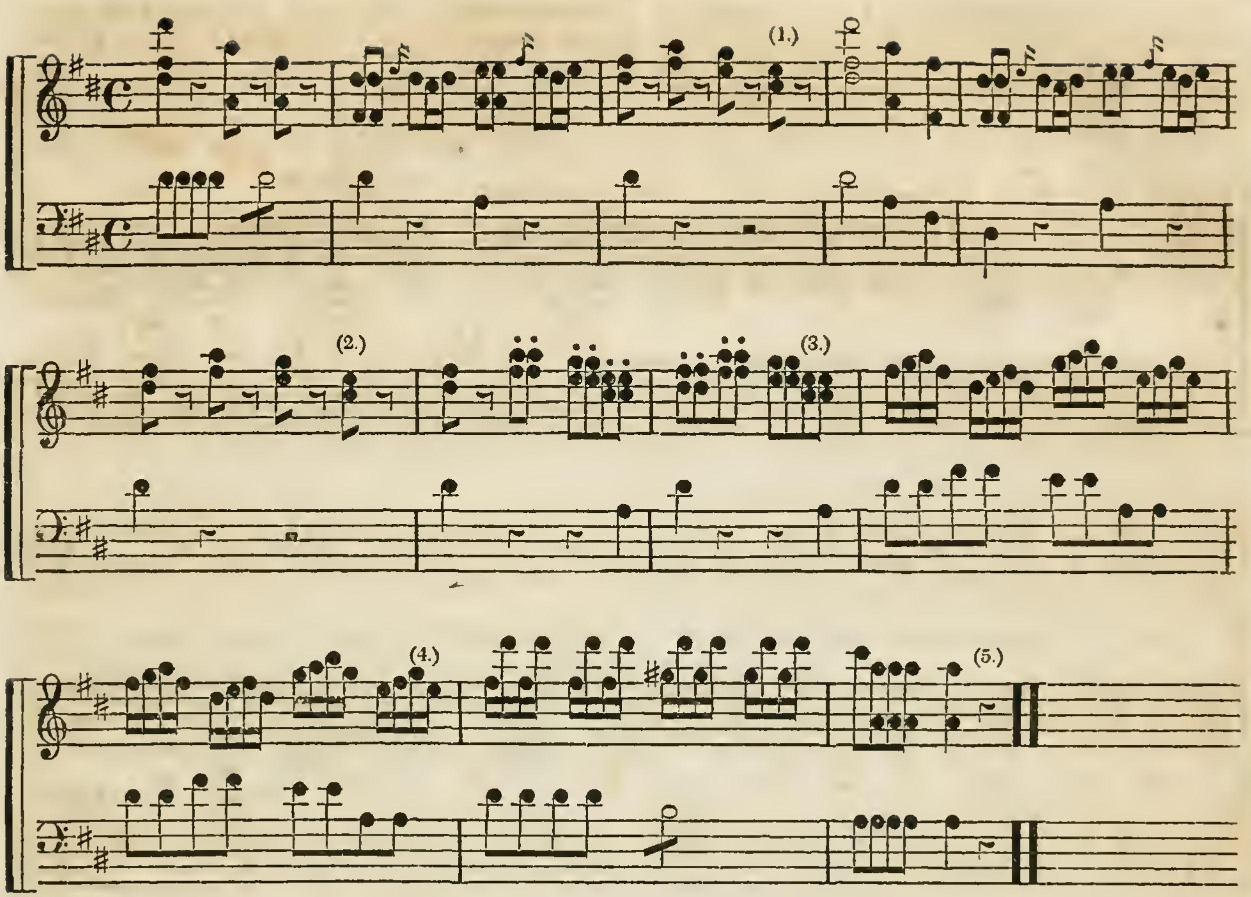
210. Besides these verses consisting of two feet, or the multiples of 2, musicians frequently use verses of three feet, or *Trimeters;* and these, in all the kinds of measures common and triple, simple and compound. As we do not recollect to have met with any airs consisting entirely of trimeters, in common time, we shall begin with one or more examples of them in triple time: and we cannot give a more favourable specimen of this kind of rhythm than in the Scottish air, *Tweedside.* Thousands have sung or listened to this air, without ever remarking any thing uncommon in the rhythm, which is indeed as agreeable and satisfying to the ear as any other. Another example of the same rhythm is, *Sae merry as we hae been.* As these are in every body's hands, we set down only the first strain of each, Nos. 1 and 2. If we consider these trimeters in pairs, they give us hexameter verses of a different kind from those noted in Art. 209. Mr. Kollmann says, that periods (verses) of three measures, are not good, except when two of them come one after another, so as to make a compound period of six measures. This opinion, however, we shall afterwards see to be incorrect. Dr. Arne frequently writes his rural songs in this rhythm, as *My fond shepherds*, No. 3. In the second strain, the third verse is a tetrameter, which makes it more emphatic than the corresponding verse in the first strain; and in consequence of this the last *couplet* consists of seven feet. This union of tetrameters and trimeters we shall notice more fully by and by.


1.
Hexameter.
Trimeter.
(1.)
Trimeter.
(2.)
(3.)
(4.)
2.
Trimeter.
(1.)
(2.)
(3.)
(4.)
3.
Trimeter.
(1.)
tr
(2.)
(3.)
tr
(4.)
Trimeter.
tr
(1.)
Trimeter.
(2.)
Tetrameter.
(3.)
Trimeter.
3
tr
(4.)

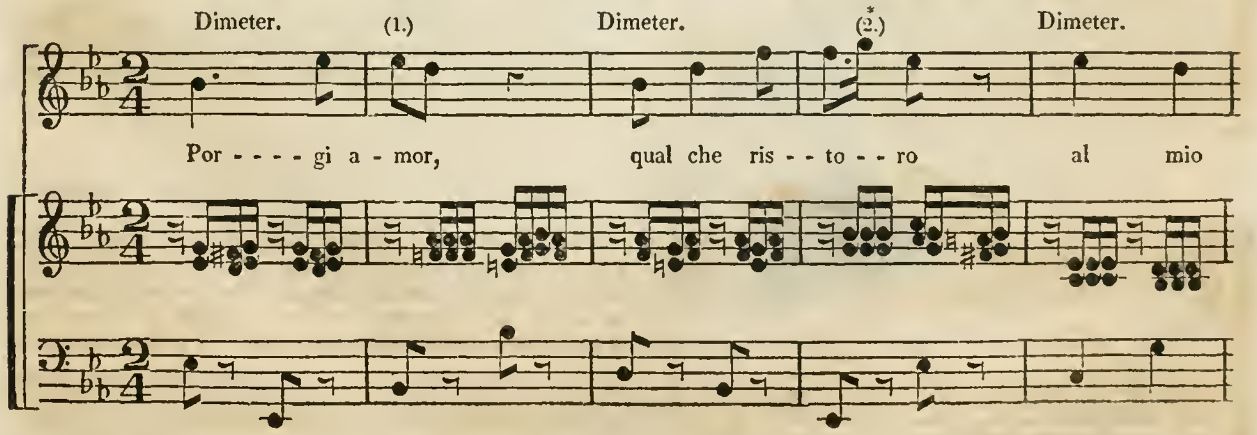
211. It would not be difficult to find many examples of airs in this rhythm of simple triple time; but the next example of an air, in trimeters of compound time, is much more uncommon. It is from Mozart's celebrated opera, *Le nozze di Figaro.* There is another strain of the same kind, which, with the remainder of the air in a different rhythm, we shall omit.

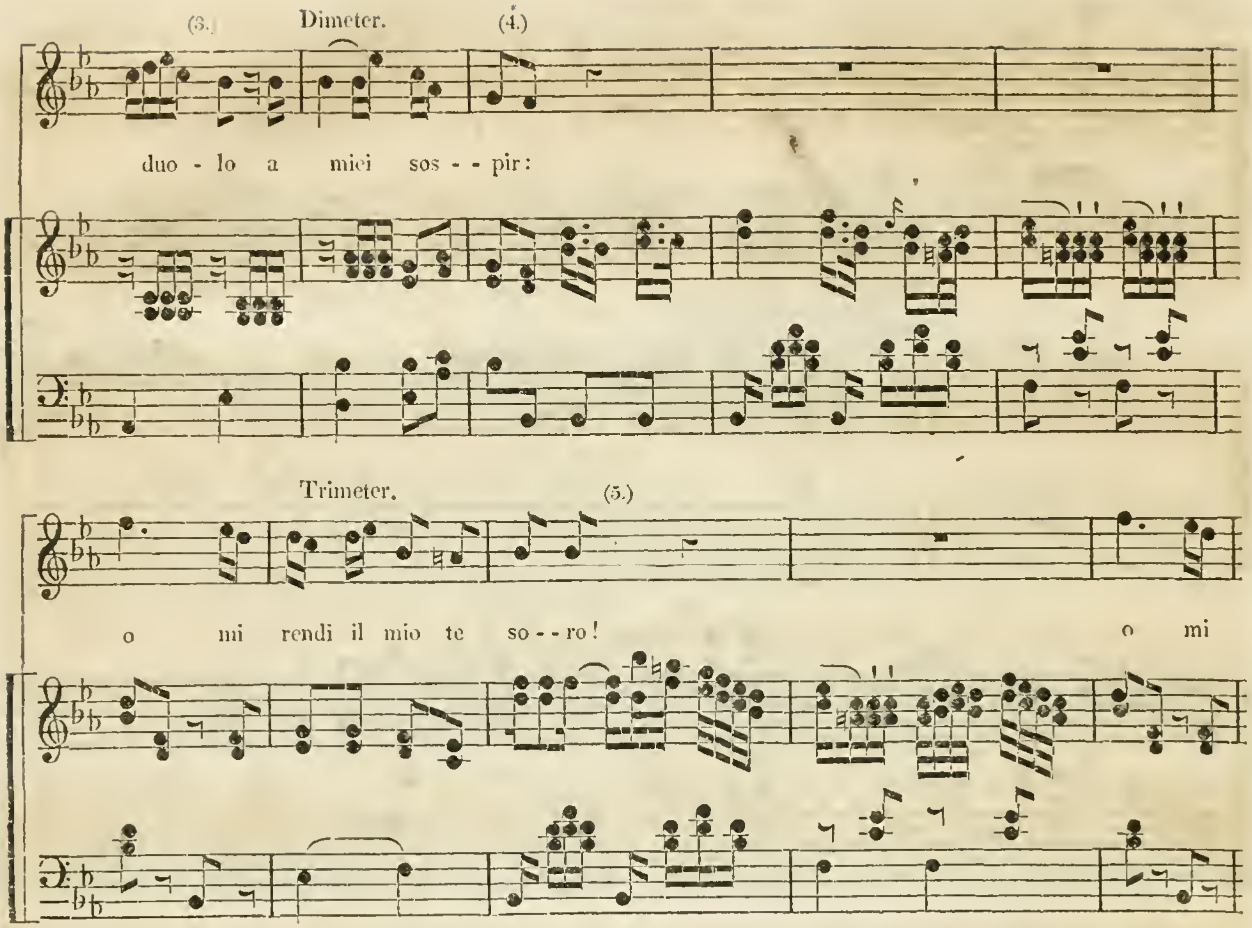

(1.)
(2.)
Deh
(1.)
(2.)
vieni, non tardar, o gio - ja bel - la, vieni ove amore per goder t'ap - pel - la, fin-
Fagotto.
Fagotto.
(3.)
(4.)
chè non splende in ciel notturna face, finchè l'aria è ancor bruna eil mondo tace.

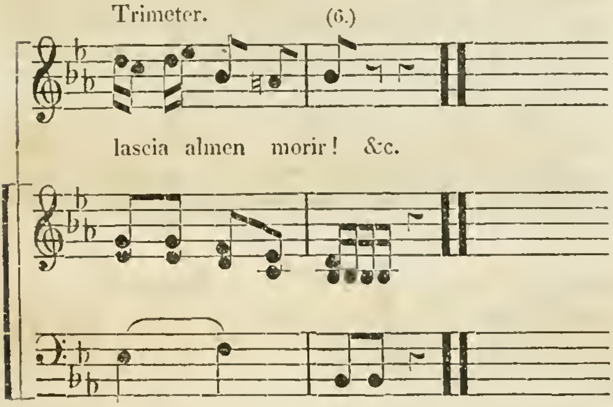
212. The Finale of Haydn's celebrated symphony in D, begins with two trimeters of double measures in common time. We quote the first stanza. The second half of the stanza, though consisting of the same number of measures or feet, contains three verses of two feet. If this were written in $\frac{2}{4}$ measures, dividing each by a bar, the stanza would consist of two hexameters, and three tetrameters.



213. Our last example shows the mixture of dimeters and trimeters in the same stanza, which is a source of great variety in the rhythm or versification of music. This is analagous to lyric versification in poetry. There is not, however, any prescribed order, according to which the different verses recur, as in the lyrics of the ancients, or as in the Italian or English stanzas. In this respect, the rhythm of longer pieces of music resembles the freedom of the English lyric poem, such as Alexander's Feast, in which the poet varies his versification so as to suit his subject; a freedom which some critics have blamed, rather from a blind attachment to the practice of antiquity, than from any good reason in the nature of the thing. Yet there are some arrangements into which musicians have fallen, unconsciously perhaps, so frequently, that we may notice them as acknowledged *stanzas.* Of this kind are four dimeters (or two tetrameters) followed by two trimeters. The vocal melody in the example (disregarding the symphonies) is an example in common time of simple measures. A similar example in common time of double measures, may be seen in the same opera, (Figaro,) *Non so piu cosa son,* which our limits prevent us from quoting.

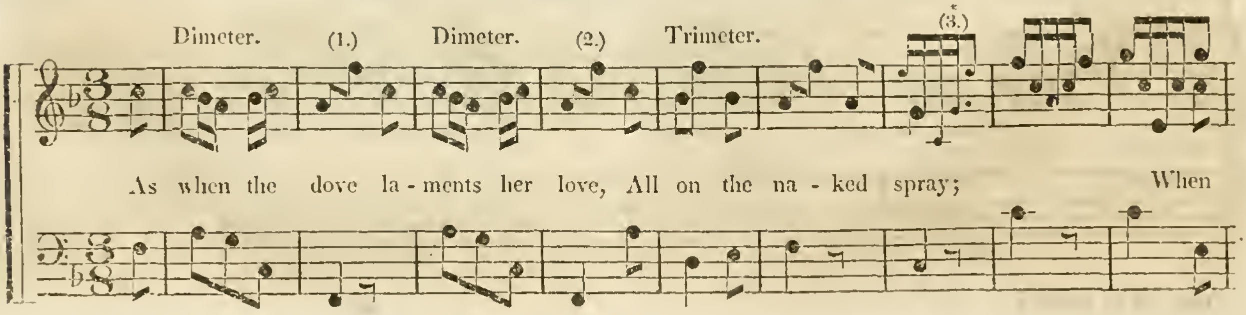


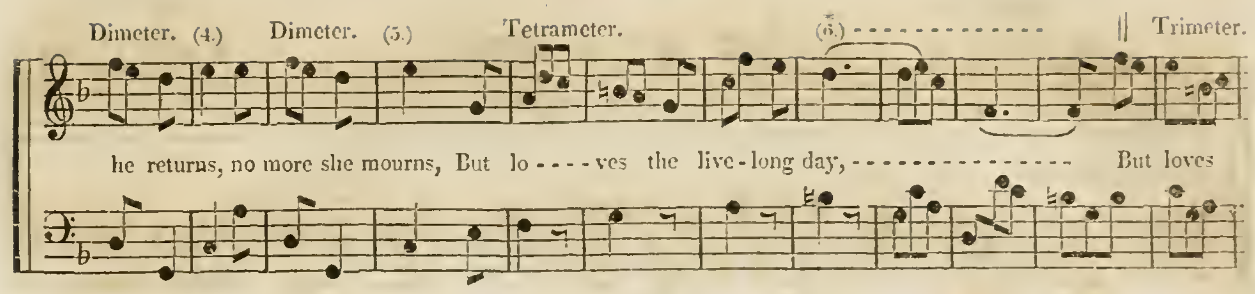


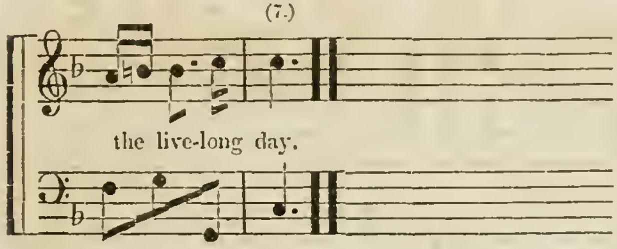


214. Two dimeters (or one tetrameter) and one trimeter alternately, make a very agreeable stanza; contrary to Mr. Kollmann's opinion cited above. This is quite analogous to our English verses of eight and six syllables alternately. Of this kind is the first half of the stanza in the example. In the second half of the stanza, however, the sixth verse is lengthened out into a tetrameter; for the lengthening of the phrase on the word *day*, we consider as not to be reckoned in the versification of the passage. It may, however, be counted a trimeter; and then the whole stanza will consist of eight verses instead of seven, as we have marked it.

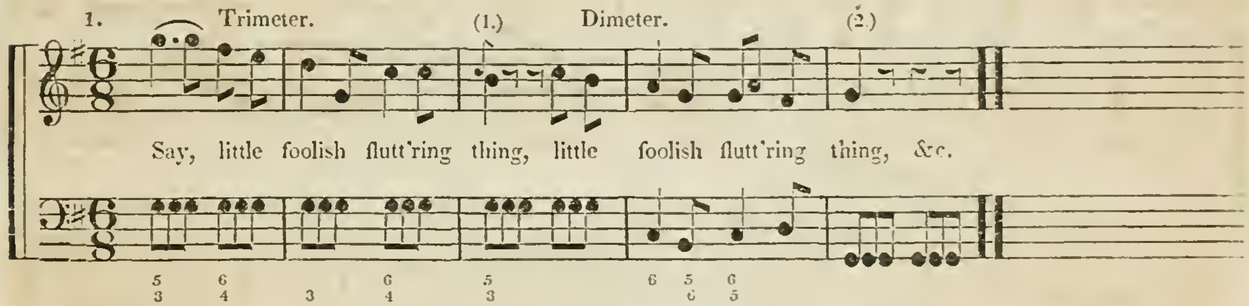
This example shows that the versification of the music is not always strictly determined by that of the poetry to which it is set. We consider it a fault in the last verse, that the word *the* is set to the first notes of the measure, by which it becomes emphatic. This, however, is not our present subject.

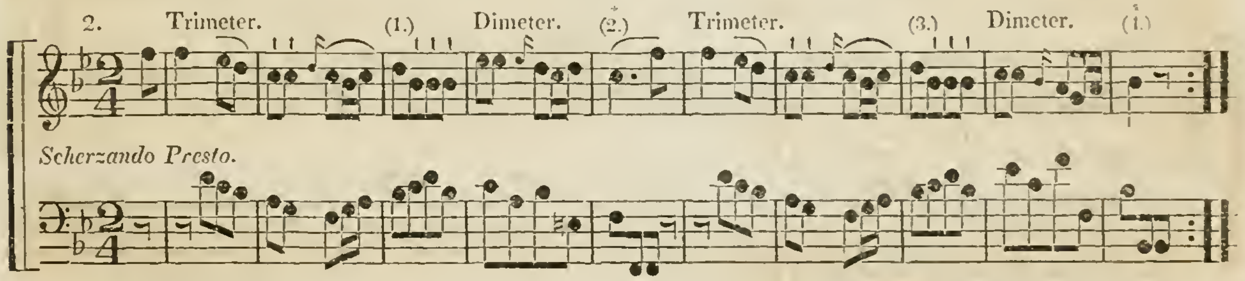

Dimeter.
(1.)
Dimeter.
(2.)
Trimeter.
(3.)
As when the dove la - ments her love, All on the na - ked spray; When


Dimeter. (4.) Dimeter. (5.) Tetrameter. (6.) Trimeter.
he returns, no more she mourns, But lo - - - - ves the live-long day, But loves

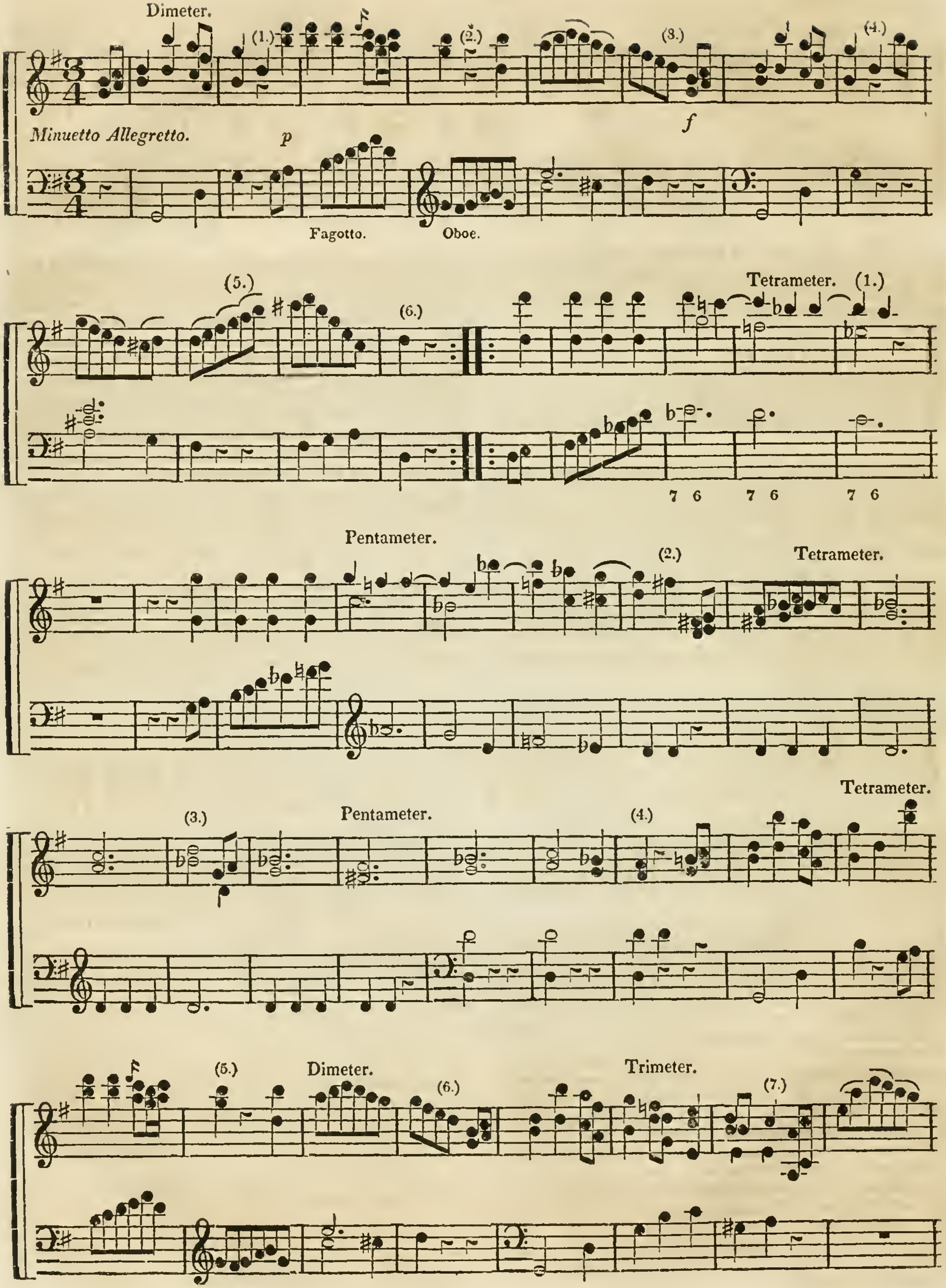


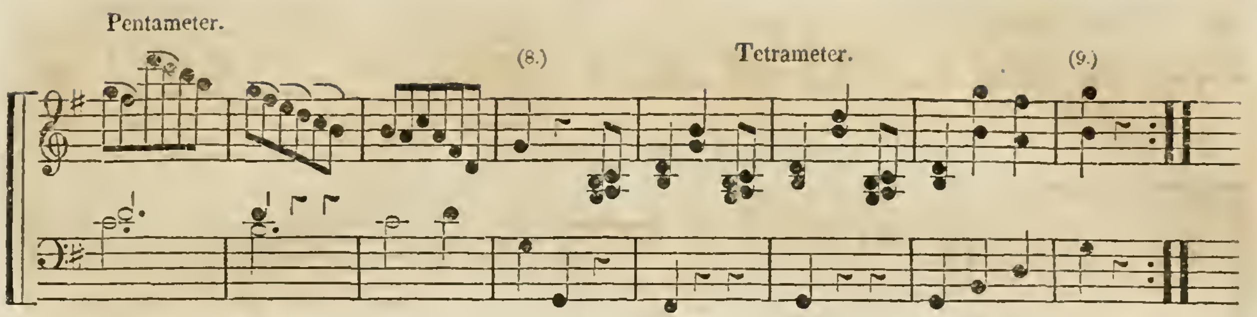
215. The union of a trimeter and dimeter forms a *pentameter*, a species of rhythm which is sometimes used with very agreeable effect; contrary to what is laid down by most writers. Thus Mr. Kollmann; "Periods of *five, seven, nine*, or still more measures of an odd number, are not allowable at all, except at the end of a section, where the odd bar may be considered as the beginning of another period; or in modulations calculated on purpose to make the ear for a short time lose the rhythmical order." No. 1 is the beginning of a beautiful little song, where this kind of versification is happily employed. No. 2 is a strain consisting of four verses, trimeters and dimeters alternately, or of pentameters. Indeed such is the union of the phrases, that, if we regard the melody only, the strain is hardly divided farther than into two pentameters. Mr. Shield, who quotes this strain, observes that they must be very fastidious who are not delighted with it and other similar examples of the same great master (HAYDN.)


1. Trimeter. (1.) Dimeter. (2.)
Say, little foolish flutt'ring thing, little foolish flutt'ring thing, &c.
5 3
6 4
3
6 4
5 3
6
5 6
6 5


2. Trimeter. (1.) Dimeter. (2.) Trimeter. (3.) Dimeter. (4.)
Scherzando Presto.

216. The following minuetto is a remarkable example of great variety of versification. The first strain we have already alluded to, Art. 209. It consists of twelve measures, which, however, do not form three tetrameters, as usual in minuettos; but six dimeters differently grouped. The two first make a tetrameter; then we have a dimeter; when the subject of the melody begins again, and the six last measures of the strain make an hexameter, or, if you please, a dimeter and tetrameter. The second strain is still more *Pindaric*, if we may be allowed the expression. As we have reckoned them, it consists of nine verses. We have first a tetrameter with a pause of nearly two measures; then pentameters and tetrameters alternately. At the fifth verse the first strain is again taken up, but with considerable variation in the rhythm: for the seventh verse (answering to the fourth dimeter in the first strain) is lengthened out into a trimeter, where it is also remarkable that the cadence takes place on the unaccented time of the measure. A pentameter and tetrameter conclude the strain.


Dimeter.
(1.)
(2.)
(3.)
(4.)
Minuetto Allegretto.
p
f
Fagotto.
Oboe.
(5.)
(6.)
Tetrameter.
(1.)
7 6
7 6
7 6
Pentameter.
(2.)
Tetrameter.
(3.)
Pentameter.
(4.)
Tetrameter.
(5.)
Dimeter.
(6.)
Trimeter.
(7.)



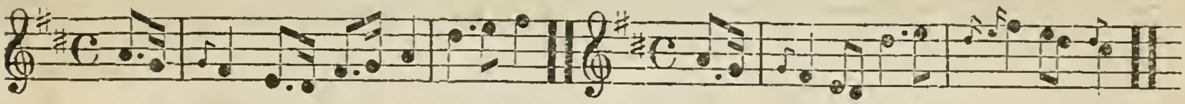
217. The use of the hard words dimeters, trimeters, &c. will not, it is hoped, be imputed to pedantry. We did make the attempt to avoid them, but we found the continual circumlocution of *verse of two feet*, &c. productive not only of disgust, but frequently of obscurity. We trust no farther apology is necessary for borrowing these terms of art from that language, which, by common consent, furnishes the technical vocabulary of all arts and sciences.

We found, on the subject of rhythm, the technical terms used by different writers so different; the same terms used in such different senses; and almost all drawn by an imperfect or false analogy from the grammar of language, that we felt ourselves warranted in attempting the reformation of it. In applying the terms of the prosody of language to that of music, we trust we have done a real service to this branch of its doctrine; that it cannot be justly said of our attempt, as the satirical poet has said of the rhetorician's rules, that they *serve only to name his tools;* but that we have really set the prosody of music in a clearer light. That, however, our readers may not be ignorant of the technical language of other writers on this subject, we shall set down, as succinctly as we can, the doctrine of Riepel and Koch, on the subject of rhythm, as given by Dr. Callcott in his Musical Grammar.

Dr. Callcott defines the musical foot as we do, 'a small portion of melody, with one principal accent, including the value of a measure.' Two feet form a regular phrase, and two regular phrases, terminated by a cadence, form a regular section. Three feet not terminated by a cadence, form an extended phrase. The contracted section differs from the extended phrase by its terminating with a cadence. The extended section may consist of five, six, seven, or more feet. A short phrase, or any other passage which does not constitute part of a regular section, but serves to connect one period or section to another, Dr. Callcott calls a codetta. A period consists of one or more sections, occasionally interspersed with independent feet, phrases, or codettas.

In these definitions, we consider it as tending to produce confusion, that the same number of feet should be differently denominated on account of the form of the harmony. The words *regular* and *irregular*, we think improperly applied; for a phrase (or verse) of three feet, as we have seen, properly used, is just as smooth and agreeable as one of two. In short, this nomenclature appears to us to have been formed on too contracted a view of musical rhythm.

The word *phrase* we continue to use, but in a more restricted sense; its proper one, as appears to us, namely, to signify the turn of the melody. An example will show clearly our meaning. These two portions of melody



are exactly the same in respect of *rhythm;* in respect of *phraseology* also they begin in the same manner, but conclude very differently, so that on the whole the two *phrases* are very different.

218. Musical verses are generally marked by CADENCES in the harmony. A CADENCE may be defined a change in the harmony at the termination of a verse; as from the dominant harmony to the tonic, or the contrary. A cadence generally takes place on the accented Time of the measure; but to this there are occasional exceptions, and, therefore, we have not included this circumstance in the definition.

The most conclusive of all cadences, is the progression of the domidant to the tonic harmony, both chords being fundamental. See Art. 104. With this cadence, almost every composition concludes; and it is unnecessary to bring examples. The concluding harmony is generally in the position of the octave highest: sometimes the third is highest; but the position of fifth highest, as being the least conclusive, is very seldom found in the last chord of a composition.

The discord of seventh, in the leading chord, contributes by its resolution, to make the cadence more conclusive; but it is not essential to the conclusive effect. The fourth and sixth cadence for instance, described Art. 117, is one of the most conclusive cadences, though it consists of common chords only, with the suspension of fourth and sixth.

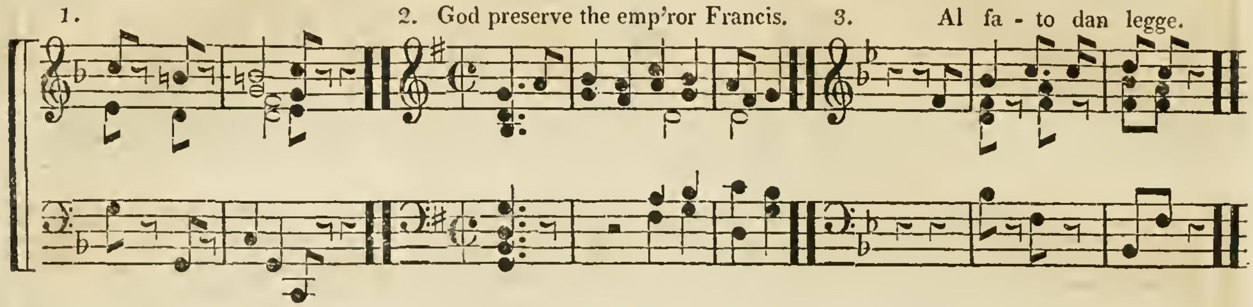
The leading harmony in the cadence, is generally on the unaccented Time of the measure, and the change or cadence, takes place on the accented Time.

A seeming exception to this rule, is the suspension of the resolution, as in Art. 199, No. 1, *j*. We shall repeat it here, No. 1.

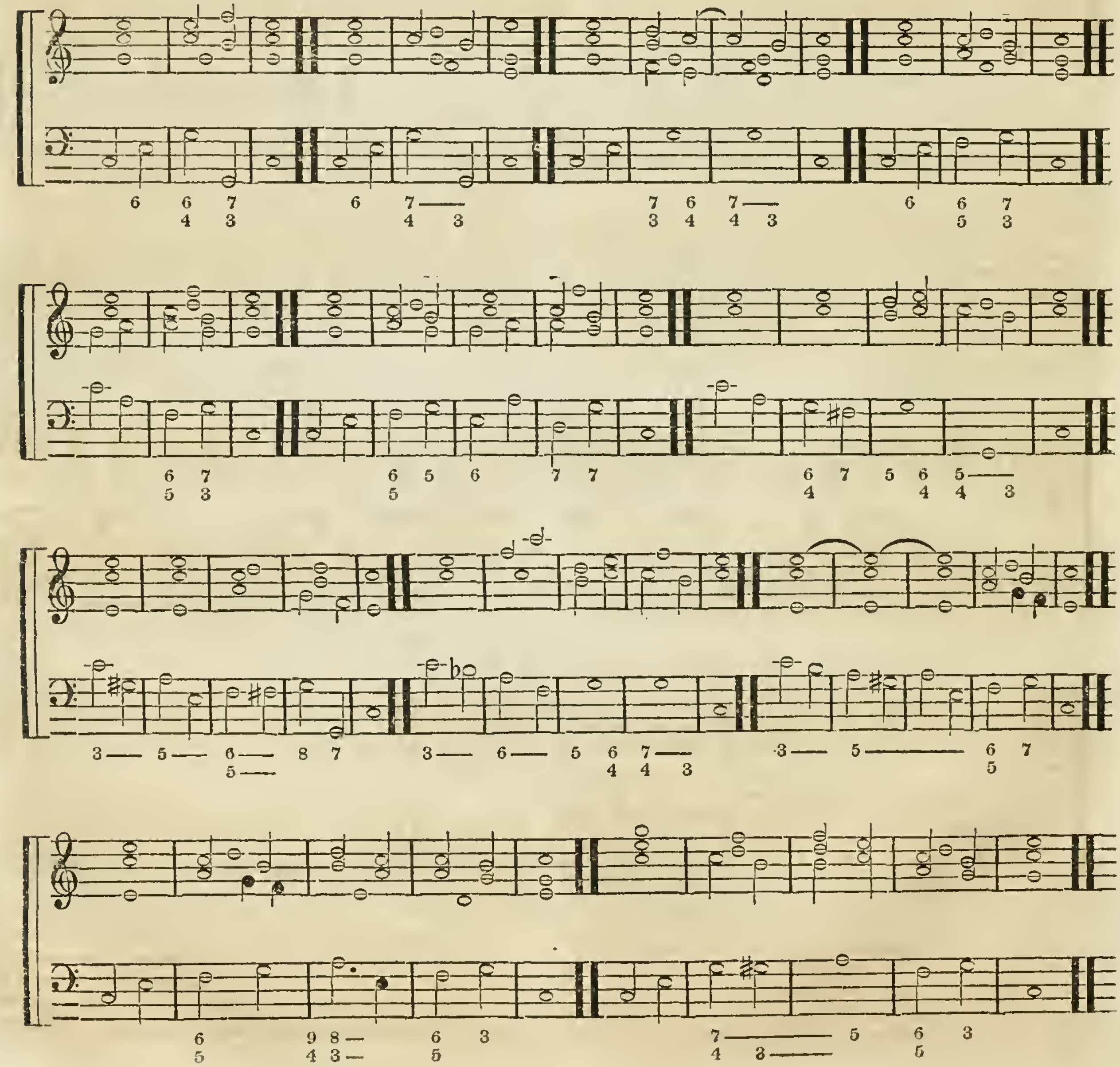
A real exception frequently takes place in musical verses set to words of double rhymes, as in the first verse of Haydn's hymn for the Emperor Francis, No. 2. Here there is a kind of double cadence, first, in the progression from the tonic to the dominant on the accented Time, and secondly, from the dominant to the tonic on the unaccented Time. No. 3 is a similar example, only that the first cadence, and the second on the unaccented Time, is the imperfect cadence from the tonic to the dominant chord.

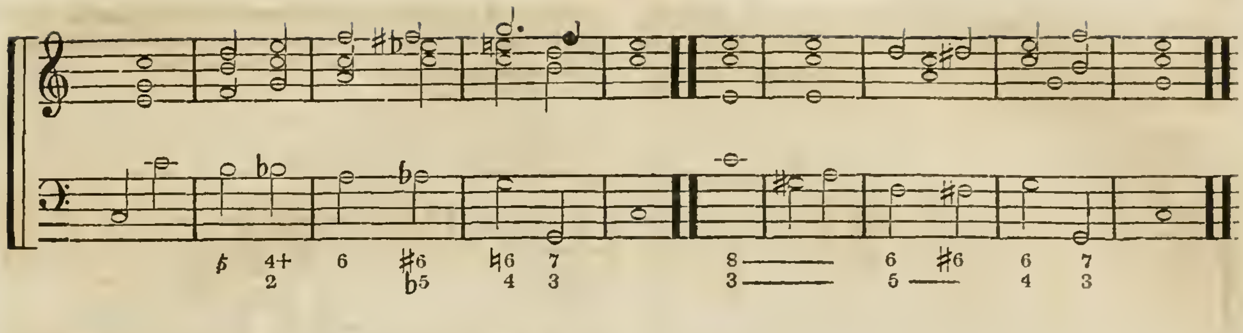
We shall set down from M. Catel the most usual progressions in the bass for introducing the perfect cadence, No. 4. The same examples may be applied to the minor mode.

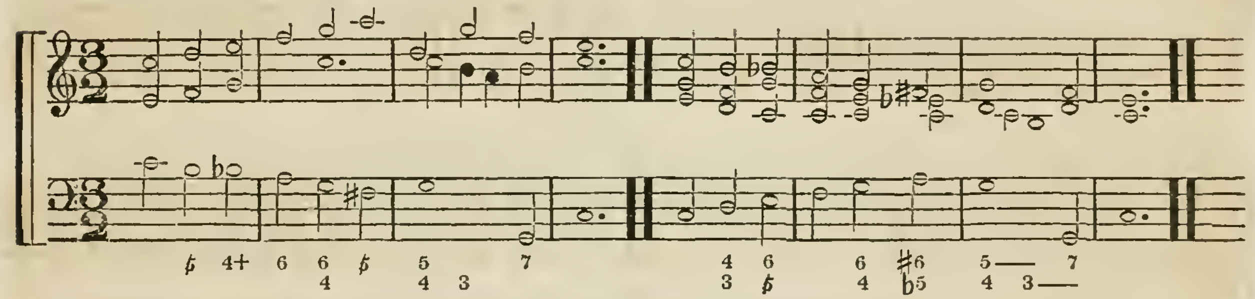
The inversions of this progression are also used as cadences to terminate verses. The first inversion is what Dr. Callcott calls the cadence of the leading note. This cadence is used in the third verse of the example, No. 2, Art. 220; where the reader will observe that the cadence takes place at the beginning of the measure, and the same harmony is continued to the end of the verse, or phrase in the melody. The second inversion, Dr. Callcott calls the cadence of the *sharp* (major) *sixth.* With this cadence, both the strains of the minuet, Art. 203, No. 14, are concluded.



4.

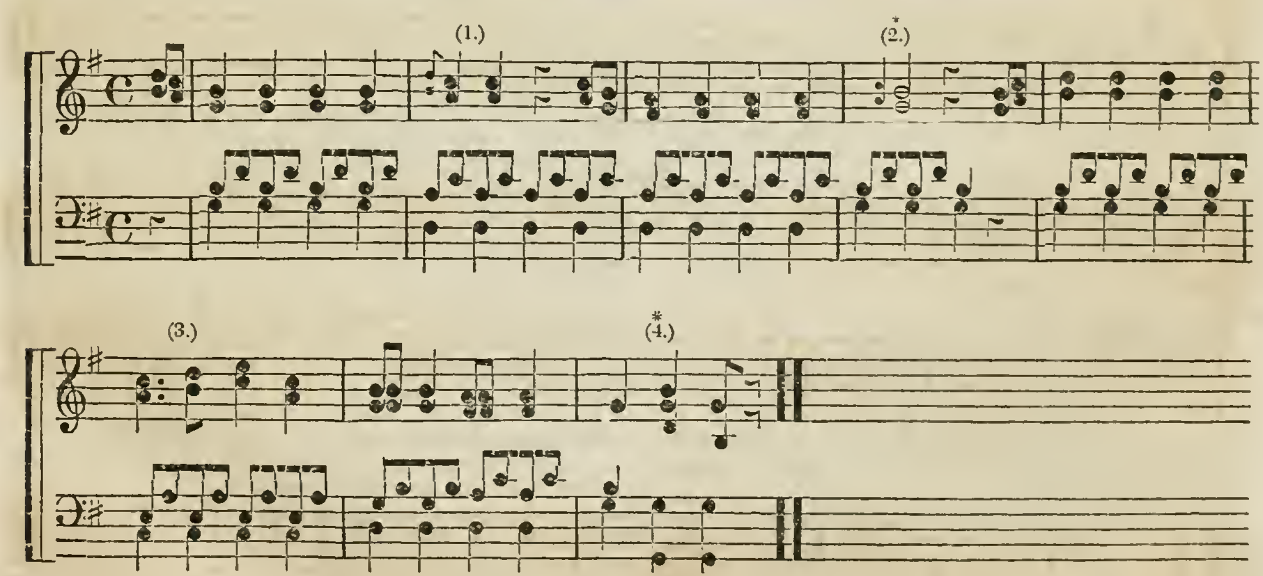






219. The tonic chord followed by that of the dominant at the end of a verse, forms the *imperfect cadence.* Dr. Callcott says, that the dominant chord to which the cadence is made, has not its added seventh. But in the middle of a strain, the seventh is often given to the dominant, which serves, by making the cadence less conclusive, to keep up the hearer's attention. Thus in the example, which is the first strain of *Away with melancholy*, the first verse is terminated by this cadence to the dominant with its seventh.

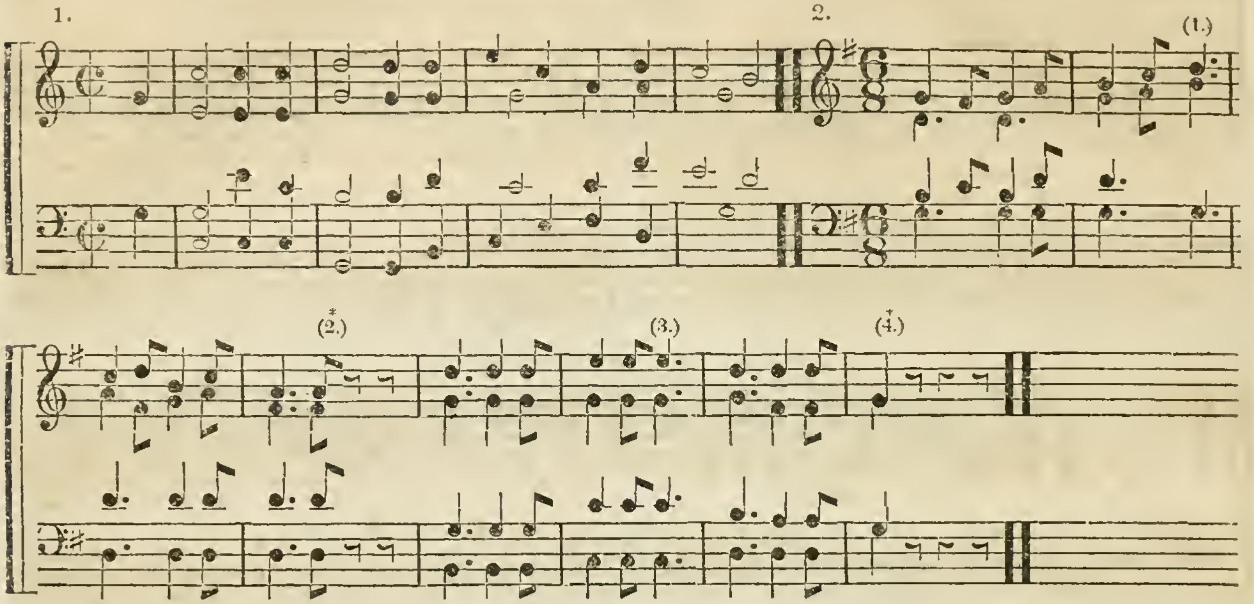
The progression of the common subdominant chord on the fourth of the key to the tonic, is this imperfect cadence in another part of the scale. This is frequently practised in church music, especially in fugues, and is called the *plagal cadence*, as the perfect cadence is called the *authentic.* This plagal cadence, is sometimes in the church style used as a final cadence, as in the *Hallelujah chorus.* When this is used in the minor mode, the tonic harmony, to which the cadence is made, is always major, by an accidental sharp or natural.



220. The subdominant chord proceeding to the dominant, forms what Dr. Callcott calls the mixt cadence. Under this, we include the common chord; the chord of sixth, or of fifth and sixth on the fourth of the key; or the chord of the second of the key, with or without its seventh, proceeding to the dominant. An example of the last, is in the chorus the *Heavens are telling*, at the close of the second verse. This example we shall set down, No. 1; but our limits will not allow us to exemplify all the variety of cadences. The preceding examples in this chapter, render this less necessary. The ver-

sification being marked, every reader may easily study the cadences by which each verse is terminated. We shall, therefore, only add to what we have said, that sometimes the verse is not concluded by any cadence in the harmony. Thus in No. 2, the first verse consists entirely of the tonic harmony, and the second verse entirely of the dominant harmony; or, in other words, neither of these verses is concluded by a cadence.

1. 2.



221. We have formerly more than once observed, that it is the combined effect of rhythm, and of the change in the harmony, which forms a cadence; an observation which we do not recollect to have met in any writers on the subject of music. We can easily show the truth of the observation, by referring to one or two of the preceding examples in this chapter. In No. 1, Art. 207, the first dimeter is terminated by the cadence of the dominant chord of seventh on the tonic, which is unquestionably, in itself, the most conclusive of all. The second dimeter again, or the first tetrameter, is terminated by the cadence of the subdominant common chord on the dominant; yet the effect of rhythm is such, that this conclusion more forcibly arrests the attention than the former. The change from the dominant to the tonic, or the contrary, at the beginning, or in the middle of a verse, is not noticed by the ear as a cadence at all. Thus in No. 2, Art 220, the change from the tonic to the dominant, at the beginning of the second verse, though it entertains the ear by its variety, is not felt as a cadence. The expectation is alive, and the ear feels more of a conclusion at the end of the second verse, where there is no change of harmony.

222. Air is distinguished from recitative, as we have observed, Art. 179, by the nature of its MODULATIONS. In air there is a PRINCIPAL KEY, in which it begins and ends, and to the harmonies of which the notes of the greater part of the melody, (except passing notes,) belong. The harmonies employed, and the manner in which they succeed each other, constitute the modulation.

A composition generally begins in the tonic harmony; sometimes, however, the dominant chord begins. In one symphony, in the key of C, Beethoven begins with the chord of minor seventh to that note, making it a dominant, and the first cadence is made in the key of F.

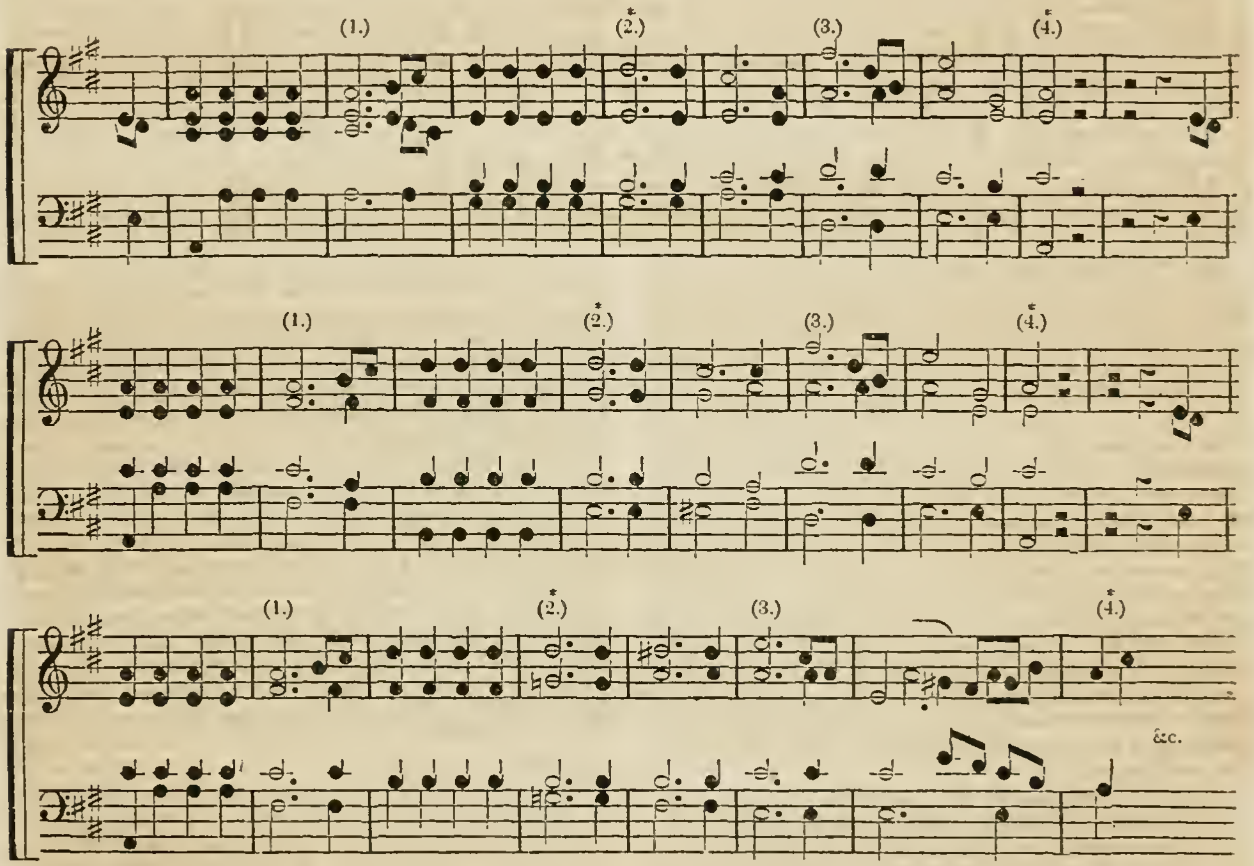
Modulations are either entirely within one key, or they pass into other keys more or less related to the principal one. The reader already knows the chords belonging to each key. The most important are the tonic and the dominant chords, and of these, modulations within the key, chiefly consist. The next are the subdominant, and the chord of the relative minor to the major principal, and the relative major to the minor principal. After these, the other chords found within the scale, not excepting the imperfect chord on the seventh of the major scale, or on the second of the minor scale; and the reader knows the discords that may be taken along with these chords. It is evident, that by the ways in which these chords may be intermixed, there may be very considerable variety in modulations, strictly confined to one key. The strain in Art 219, is an example of the most simple modulation within the key. The first measure consists entirely of the tonic harmony, which, at the beginning of the second measure, makes an imperfect cadence on the dominant chord of seventh. This harmony is continued throughout the second and third measures, and at the fourth, makes a perfect cadence on the tonic, concluding the first *distich.* The tonic harmony is continued through the fifth measure, and then makes a cadence on the fourth of the key, with chord of fifth and sixth. This harmony is followed in the seventh measure by the dominant with fourth and sixth, and third and seventh; and this in the eight measure makes a final close on the key. The example, No. 2, Art. 220, consists of the same harmonies, yet the modulation is somewhat different. The two first measures, overlooking the passing notes, consist entirely of the tonic harmony, and the third and fourth measures of the dominant; and there are no cadences. The second verse, concluding with the dominant chord in the position of fifth, keeps up the attention; and this is more usual in the middle of a strain than a cadence on the tonic, as in the former example. The modulation in the two last verses is the same as in the corresponding verses of the preceding example, only that the dominant harmony is inverted in the beginning of the fifth measure.

The modulation of the example, No. 10, Art. 203, is considerably different from these, though still entirely within the principal key. The chord of the tonic becomes by the diatonic dissent of the bass, the discord of second, conducting to the relative minor in the beginning of the second measure;

this harmony is in the latter part of the measure, succeeded by the first inversion of the tonic. In the third measure, we have the chord of the second of the key, which, in the fourth measure, makes a cadence on the dominant chord. The same passage is repeated, and then the strain concludes with a verse of three feet, making the 4th and 6th cadence on the key. The strain thus consists of two tetrameters and a trimeter, comprehending eleven measures.

The modulation in the first strain of the minuetto, No. 2, Art. 209, is chiefly remarkable by the cadence at the end of the first tetrameter, (or second dimeter,) being on the subdominant harmony. This place is much more usually occupied with the dominant chord. The examples in Art. 207 to 214 inclusive, are chiefly within the principal key; and we shall leave them to the reader's study.

223. The same air may, by the disposition of the harmony, be made to belong to different modulations. The example is a chorus in Haydn's Oratorio of the Creation, where, in the several repetitions, he varies the harmony, or modulations. In the first instance, the modulation is the same, with the exception of some inversions, as in No. 2, Art. 220. In the first repetition, the first verse ends with an *interrupted cadence*, (see Art. 167,) of the tonic on the relative minor. Thence the modulation goes by diatonic sequence of descending fifths and ascending fourths in the bass to a cadence on the dominant chord of seventh at the end of the second verse. Thence, by the chromatic rise in the bass, the modulation passes for a moment into the relative minor, but immediately returns by the subdominant of the principal. Though in these two instances the melody in the highest part is the same, the change in the modulation makes a very considerable difference in the effects. In the next repetition, not only the modulations are different, but the air is altered in the two last verses.



224. Transitions from the principal key into other keys, are made by means of the dominant of the new key resolving on its tonic. They are either transient, as in the last example, the principal key being immediately resumed, or the new key is more or less formally established, and the modulation proceeds in it for some time. A new key is formally established when it is first *announced* by the accidental sharp, which is its sensible note, or by that accidental flat which is minor seventh in its dominant chord, and afterwards a perfect cadence or close in that key takes place.

Changes of key are either *natural* or *extraneous*. Natural transitions or modulations, as they are usually called, are to such keys, whose scale differs from that of the principal, by no more than one sharp or flat: and to every key there are five keys thus related, viz. the relative minor or major, the fifth with its relative, and the fourth with its relative, each in that mode which the primary scale gives it. To a major principal key and its relative minor, the related secondary keys are the same. Thus, to C and its relative minor A, the related keys are G major, F major, with their relatives E and D minor.

From the major principal, the first transition is usually to the fifth of the key, and in a piece of considerable length, the last before returning to the principal key is generally the fourth. But there is not any prescribed order. Albrechtsberger lays down the following as the most general order:

"From the major principal we pass to the fifth of the scale major mode, thence to the sixth minor mode, then to the fourth major mode; which brings to the second minor mode; lastly, we pass to the minor mode of the third of the scale. When we have finished this course through the related modes, we must endeavour to return to the principal mode, in which we ought always to terminate after every modulation, whatever be its length.

"This formula of modulation will be better understood by an example. From C major we should pass to G major, thence to A minor, then to F major, to D minor; and lastly, to E minor, in order to conclude in C major with which we commenced.

"Modulation in the minor mode follows a different order. From the principal mode we prefer passing to the relative major, for example, from A minor to C major; from this to the seventh of the principal scale, major mode, that is to G major; thence to the fifth E minor, thence to the fourth D minor, thence to the sixth F major, whence we return to the principal key A minor.

"The order, however, which we have prescribed, is not obligatory, and every one may follow that which pleases himself."

"It is difficult," says M. Catel, "to prescribe rules for the course of modulation. The only one, from which we ought never to depart, is to satisfy the ear. This is the essential object of music, and rules are created only for attaining it."

225. Beyond the circle of five related keys, all transitions are extraneous, and were forbidden by the older masters. The modern masters, however, have produced the most delightful effects by setting aside these rules. Distant keys may be brought in gradually, as by a sequence of dominants, or by first going to a related key, and then passing to new keys related to this, but more distant from the principal. Thus, by going from C major to G, we may thence pass to D major, or to B minor, or by going from C major to F, we may thence pass to B♭ major or G minor.

From the rule which estimates the distance of one key from another by the difference of sharps or flats at the clef, there is one remarkable exception, namely, a transition from the major mode of any note to the minor mode of the same, or conversely. The key-note and dominant chord remaining unchanged, these two modes are nearly related, and the transition cannot be called extraneous. Now, by this change, a great variety of secondary keys are brought as it were into relation with the principal key. Thus to the key of C major besides its own five related keys, by passing to C minor we have immediately another circle of five keys, E♭ major, B♭ major, G minor, F minor, and A♭ major. Nor is it absolutely necessary first to pass to the minor of the tonic. Thus, in a *Finale* in the principal key of B♭ major, Haydn closes the first strain, or first part in F the fifth of the key. The second strain begins on D♭ major, (as if the primary key had been B♭ minor,) and thence he goes to E♭ minor. After a close on this key, by a chromatic change of G♭ to G♮, the chord of E♭ major brings him home again. So in his Canzonette RECOLLECTION, the principal key of which is F major, having brought in the chord of G major, as if going to C major the fifth of the key, he gives the happiest surprise by carrying the modulation to C minor.

Distant changes of key are immediately effected by means of the enharmonic changes of the chord of diminished seventh, which we have fully explained in Chap. VII. We did intend to have illustrated this subject more fully, and we had marked appropriate examples for quotation from the works of the best masters. But our limits exclude these, and oblige us to be contented with having given these hints, and with referring the reader to the scores of Haydn, Mozart, Beethoven, &c. We shall conclude this part of our subject by quoting a very just remark of M. Gretry, which furnishes an important hint on the subject of distant modulation.

"The music of Haydn may be regarded as a model in the instrumental style, on account of the fecundity, both of his subjects of melody and that of his modulations. The abundance of the means would perhaps render him dry. (*abstrait*) if he did not, as seems to me, observe a kind of rule, which consists in preserving long the same trait of song when he makes many changes of modulation; but he is rich in melody when his changes are few."

226. The last characteristic of air which we mentioned, Art. 179, was *Subject*, which we explained to be the same, or similar turns or phrases of the melody returning more or less frequently. It is *subject* which gives individuality, we had almost said existence to air. Without it there may be melody; a song disposed in good modulation, with good harmony, and in rhythmic order, may be pleasing for a time; but if there be no subject, such melody will be vague and uninteresting, and will soon cease to please. It is the subject which most effectually shows design or method in the disposition of the melody, and gives it meaning. When an unpractised hearer listens to a new piece of music, he is at first perplexed; but when he begins to recognize the phrases, and mark their returns, he says he now begins to *understand the tune.*

"All the other branches of music," says Rousseau, "require only art and labour; this alone depends on genius, and it is in this that invention consists." This most important part of the art, therefore, is least of all capable of being taught by rule. Accordingly, no writer that we are acquainted with, has made any such attempt. We shall therefore be contented with analyzing the subjects of one or two of the airs in this chapter.

The first strain of the air, No. 2, Art. 207, is divided into two *distichs*, as shown by the asterisk over the (2,) and in each of these, the first verses, (the (1) and (3) of the strain) are exactly the same. The conclusion of the first half is in the harmony of the dominant, keeping up the attention; that of the second, by a variation of the 4th verse, conducts to a close in the key. The first half of the second strain is a new phrase repeated with a slight variation in the last measure of the second verse; the second half is the same with that of the first strain. Here all the phrases are clear and easily taken up by the ear; they are congruous, and run sweetly into each other; and the union of the whole forms a pleasing and attractive air.

The subject of No. 2, Art. 208, though extremely different in its key, measure, and phraseology, resembles the last mentioned air very much in the *disposition* of the subject as well as in the modulations. The first half of the first strain consists of two phrases, the second ending in the harmony of the dominant. The second half begins with the same phrase with the first, and by a slight variation in the fourth verse, closes in the key. The disposition of the second part of the air, does not so much resemble that of the former. The fifth verse consists of the same phrase (or semiphrase) repeated. The sixth and seventh verses are varied a little in the conclusion of the phrase, and in the cadence of the harmony; the former being a broken cadence on the sixth, and the latter a full close on the key. It would be easy to quote many examples of a similar disposition of the subject, especially in the national airs of Scotland and Ireland. But the disposition of the subject may be varied *ad infinitum.* Nor does adherence to the subject require an exact repetition or transposition into another part of the scale where the same intervals may be found in the same order. *Imitation* of the phrase in another part of the scale, where major intervals take the place of minor, and the contrary, gives variety, and at the same time keeps the subject in the mind of the hearer. Thus, in Example 1, Art. 207, the third verse is not a repetition of the first, but an imitation in a different part of the scale. In the second strain, a resemblance in the melody to the first strain is perceived, though the movement is by different intervals. This air, with variations, is in Haydn's Symphony in D; the study of it we earnestly recommend to the reader. Of this, and other airs similarly treated by this great master, we may say that the subject is gold, and the workmanship exquisite.

In longer pieces of music, such as sonatas, concertos, symphonies, &c. different subjects are introduced and variously treated. These must be congruous with the subject, admit of an easy coalescence with it, and must be kept subordinate to it, rather to heighten its effects, and make its return more welcome, than to occupy its place. As our limits preclude the possibility of exemplification, we must refer the student to the scores of the masters in the art.

CHAP. XII.

OF THE SYSTEM OF PERFECT INTONATION; AND THE ENHARMONIC ORGAN—OF THE TEMPERAMENT OF THE SCALE IN INSTRUMENTS WITH FIXED SCALES.

227. MUSICAL instruments of the violin kind have no fixed scale: the pitch of the sounds drawn from them is entirely at the command of the performer. They are, therefore, *perfect* instruments in respect of tune. Keyed instruments, on the contrary, having a fixed scale, limited to a much smaller number of notes than the musician requires, are imperfect. The performer is obliged to substitute one sound for another, differing from it by a small interval; and, in order to make the substitution tolerable, the whole scale is tuned in an imperfect manner. This is called the *temperament* of the scale; of which we shall give an account by and by.

Many attempts have been made to improve the scale of keyed instruments, by furnishing a greater number of sounds within the octave, so as to bring them nearer to the perfection of the violin tribe. It is only within these few years that the scale of the organ has been brought to absolute perfection.*

228. Keyed instruments, in general, have only twelve sounds within the octave, while musicians universally acknowledge at least twenty-four, as the reader has seen in the course of this treatise. Hence the necessity of the same sound serving for C♯ and D♭, G♯ and A♭, D♯ and E♭, &c. &c. as explained Arts. 87 and 161. The learned Dr. Smith, Master of Trinity College, Cambridge, about the middle of last century, proposed in his HARMONICS to remedy this defect by supplying twelve additional sounds; so that at the will of the performer, each finger-key might give either of the two sounds of the enharmonic diesis, as shown in the table, Art. 161.

Let the twelve finger-keys give the sounds, C, C♯, D, E♭, E, F, F♯, G, G♯, A, B♭, B, which may be called the original scale. It comprehends, therefore, three sharps and two flats. All the sharps beyond these three, viz. D♯, A♯, E♯, B♯, F×, C×, Dr. Smith called extreme sharps; and all the flats beyond these two, viz. A♭, D♭, G♭, C♭, F♭, B♭♭, he called extreme flats. Now, he proposed to introduce these extreme sharps by pairs. If, for instance, a piece of music were to be performed in E major, the E♭ of the original scale would be too acute, as major third to B, or as the sensible note of the key; we must have D♯ very considerably flatter than E♭. But when we bring D♯ into the scale, we may, without any inconvenience, at the same time bring in A♯ in place of B♭, because this last sound can never be required along with D♯. One pedal may therefore make this substitution of D♯ and A♯; which pedal being released, the two original sounds, E♭, B♭, will return. It is plain, also, that by means of this pedal, the enharmonic change of E♭ to D♯, and of B♭ to A♯, or the reverse, may be made in such transformations of the chord of diminished seventh, as have been explained Arts. 162, 166. After the same manner, a second pedal may substitute the next pair of extreme sharps, E♯, B♯, for their corresponding sounds in the original scale, F and C; and when this pedal is pressed, it may always take with it the first extreme sharp pedal, because we can never require E♭ and B♭ along with E♯ and B♯. Yet we could not make one pedal serve for both, by introducing the four sounds, A♯, D♯, E♯, B♯, at once; because we may require C and A♯, or C and D♯, or A♯ and F to be struck in chord, which would then be impossible. So also a third pedal may introduce the next pair of extreme sharps, F×, C×, for G, D; and this third implies the other two, though one pedal could not serve for all, for similar reasons to those stated.

After the same manner, the six extreme flats may be introduced into the scale by pairs. The first extreme flat pedal substitutes A♭, D♭, for G♯, C♯; the second substitutes G♭, C♭, for F♯, B; and the third, F♭, B♭♭, for E, A. The observations made above, are equally applicable to these substitutions.

As these substitutions proceed in an order familiar to musicians, being the same in which the sharps or flats occur at the clef in a series of keys proceeding by fifths, (Arts. 80, 90,) they cannot occasion embarrassment to performers of any intelligence.

229. The scale of keyed instruments thus furnished with twenty-four sounds within the octave, is still far from being perfect. We have observed, Art. 69, that the diatonic scale, as tuned on keyed instruments, is imperfect, and that, when the series of sounds is taken exactly as the ear desires them to be, other distinctions besides those of tone and semitone are found among the elements of that simplest scale of music, and this matter we are now to explain.

If to any note C we tune G perfectly true as fifth; and to G tune d perfectly true as fifth, and then take D perfectly true as octave below d, we have the second note of the diatonic scale; and the interval C D is *major tone;* the reason of the epithet *major* will appear immediately. Now, suppose we should, in the same manner, proceed from D, and tune *A* perfect fifth; and to *A* tune e perfect fifth, and from e take *E* octave downwards, it is manifest that this *E* would be major tone above D, and the whole interval C *E* would consist of two major tones. But, on trying this interval as major third, it is found extremely bad; the *E* is considerably too sharp. Let E then be tuned major third to C, so as perfectly to satisfy the ear, it is plain that the interval D E is smaller than D *E* or C D, the major tone; it is therefore called the *minor tone*, and the excess of C D or D *E*, above

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* The instrument here alluded to, and called by Mr. Liston, the inventor, the ENHARMONIC ORGAN, has already been noticed by Mr Farey, senior, in our article ENHARMONIC ORGAN.—EDITOR.

D E, or the difference between the major tone and minor tone, is called *comma*.

If now we take F perfect fourth to C, or perfect fifth below the octave c, we fill up the fifth with the sounds of the diatonic scale; and the interval EF is what, in the preceding pages, we have called the diatonic semitone, though it is really very considerably greater than half of the major tone.

It remains to fill up the interval of fourth from G to C. On comparing *A* tuned perfect fifth to D, it is found considerably too sharp as sixth of the scale; but if we take a perfect major third to F, we find this perfectly satisfactory as sixth to C.

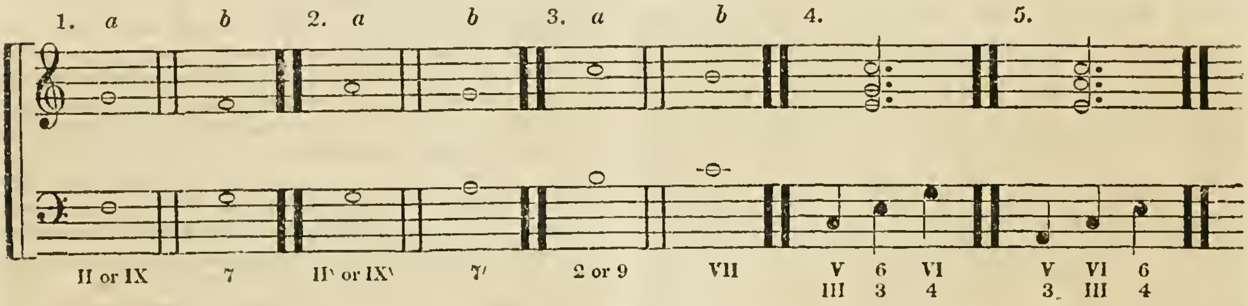
Lastly, by tuning B major third to G, we have the seventh of the scale; and it is plain that the interval Bc, being the difference between the major third and perfect fourth, is a diatonic semitone, like that between E and F.

230. The elements, or smallest parts, then, of the diatonic scale, when truly tuned, are three, tone major, tone minor, and semitone, to which we add the epithet diatonic, to distinguish it from others found in the Chromatic scale. These elements are arranged in the following order: C to D, tone major; D to E, tone minor; E to F, semitone; F to G, tone major; G to A, tone minor; A to B, tone major; B to C, semitone. The whole octave, then, contains three major tones, two minor tones, and two diatonic semitones.

231. Besides the distinctions, then, of seconds, ninths, and sevenths into major and minor, formerly described, Art. 77, we have, in this perfect scale, new ones arising from the difference of major and minor tones. The greater tone forms major second or major ninth, which in the subsequent examples we shall figure II. and IX.; and this second inverted gives minor seventh, which we shall figure 7, No. 1, *a*, *b*. The minor tone again gives another species of second or ninth, to which the epithet *major* is still continued, (because the name *minor second* belongs to the diatonic semitone,) but the difference is denoted by the addition of *grave*; the grave major second, and grave major ninth, which we figure II‵. and IX‵. This second inverted gives another species of minor seventh, more acute than the former by comma, which we figure 7′, No. 2, *a*, *b*. These seconds, sevenths, and ninths, belong to different combinations, as we shall see immediately. The diatonic semitone is the minor second or ninth, figured by the Arabic numerals 2 and 9. The inversion of this second is the major seventh, figured VII., No. 3, *a*, *b*.

The major third consists of the greater and lesser tones, which we figure III. By inversion, it is the lesser sixth, figured 6. A third, consisting of two greater tones, or of two lesser tones, is intolerably harsh, and inadmissible in any combination.

The perfect fifth consists of major third and minor third. This minor third consists of the greater tone and diatonic semitone, figured 3. Its inversion is the major sixth, figured VI. The common chords, major and minor, with their inversions, are such as are figured in Nos. 4 and 5.



232. The true interval of fifth, therefore, consists of two major tones, one minor tone, and semitone; and in the diatonic scale, tuned perfectly as above directed, all the major fifths are of this quantity, except that from D to A, which will be found to contain one greater tone, two lesser tones, and semitone. It is flatter than the true fifth by the difference between the greater and lesser tones, that is, by comma. The effect of it is altogether intolerable in any chord.

The chord to D then consists of a species of minor third DF, made up of lesser tone and semitone, and of major third FA. This species of minor third, though altogether inadmissible as part of the perfect or major fifth, is yet a true musical interval, and makes part of many chords; it is called the *grave minor third*, figured 3‵. Inverted it makes *acute major sixth*, figured VI′.

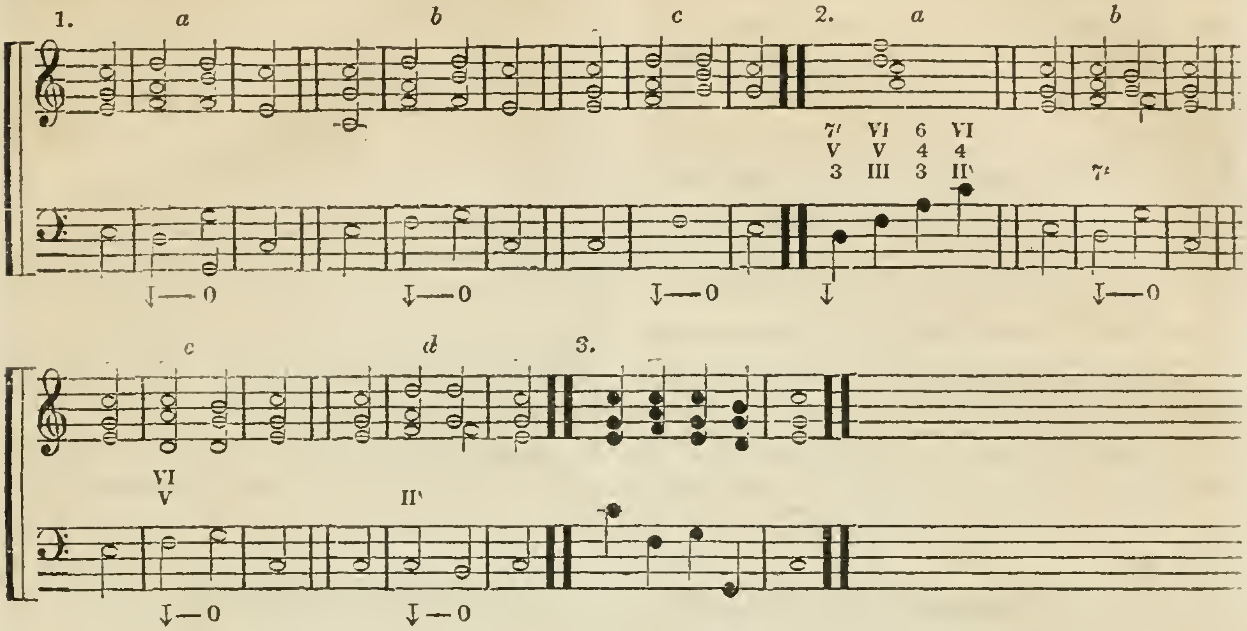
233. The second of the scale, major tone above the key-note, or its octave, harmonizes perfectly in the dominant common chord; but, it appears that it cannot harmonize with the perfect fourth, and perfect major sixth, of the scale. We ought, therefore, to have another second in the scale, perfect fifth below A, consequently comma flatter than D. This is called the grave second, and is marked with the grave accent D‵; and this new sound is perfect minor third, (consisting of greater tone and diatonic semitone,) below F. Thus, we have a true minor common chord on the second of the scale, or a true chord of major third and major sixth to the subdominant.

As the finger-board has its established number of finger-keys, the D‵ is given by the same finger-key which gives D, and the change of pitch is effected by a pedal, called a grave pedal; and marked with an arrow, pointing downwards, thus, ↓.

234. Let us now see what takes place when the subdominant harmony is succeeded by the dominant, as in No. 1, *a*. The performance is quite simple. The grave pedal is pressed when the subdominant chord is struck, and is released when the dominant comes, signified thus, ↓—*o*. In consequence of this, the D at the top of the chord rises by comma, and the bass leaps downwards by major fifth, too small by comma, or upwards by minor fourth, too great by comma, to the true fifth of the key. These movements, so far from being disagreeable, are exceedingly welcome and gratifying to the ear. The same change in the pitch of the D takes place, however the progression be inverted, as at *b* and *c*.

Let us now add the minor seventh to this common chord on D‵: it is the key-note perfect fifth to the third of the chord; and as D‵ is grave major second above C, this interval inverted is acute minor seventh. The chord, then, and its derivatives, are such as are set down, No. 2, *a*. The introduction of the discord makes no alteration on the above mentioned circumstances, *b*, *c*, *d*.

When the fourth of the key has a common chord as in the fourth and sixth cadence, no change takes place, and no pedal is required, No. 3.



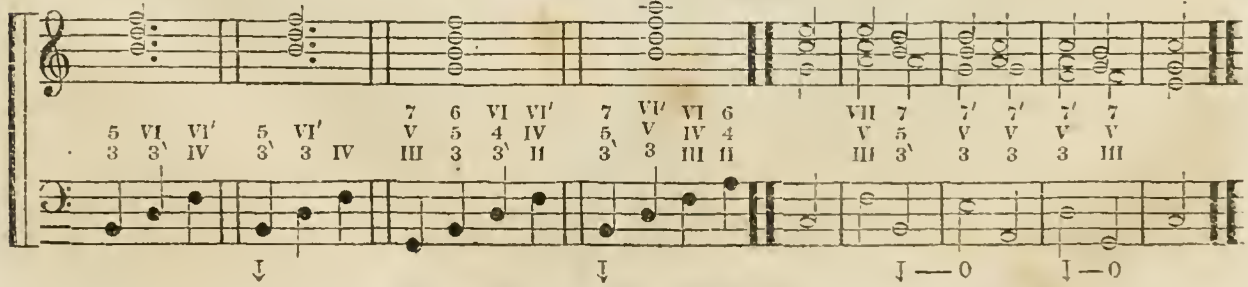
235. The minor or imperfect fifth between the major seventh of the scale, and the octave to the fourth, consists of minor third BD, and grave minor third DF. The dissonant common chord, then, with its inversions, are such as are figured in No. 1, *a*. If the second of the key be made grave, we have the lesser fifth accompanied by grave minor third. This chord, with its derivatives, will be such as are figured at *b*. These two forms of the chord are both used. They belong to different combinations. By comparing their inversions, it will be seen that when the major sixth is accompanied with minor third, either the third will be grave, or the sixth will be acute. Experiment has proved that these are the best forms of the imperfect fifth and its inversions; a lesser fifth, consisting of two minor thirds, both consisting of major tone and semitone, is a much less agreeable combination, and hardly admissible in music. The greater fourth, it appears, may accompany either the major sixth or the acute major sixth.

It is the lesser fifth, accompanied by minor third, as at *a*, which makes part of the dominant chord; for the dominant must have the second of the key, not the grave second for its fifth. And as the fourth of the key is greater tone below the fifth, the inversion of that major second gives minor seventh, (not acute minor seventh, as we had in the subdominant.) The whole chord, with its derivatives, then, will be as at *c*.

On the other hand, if we add minor seventh to the dissonant fifth, it must be accompanied with grave minor third; because such seventh being major third above the lesser fifth, can admit of no alteration, and the third of the chord must be perfect major fifth below that seventh. The chord and its derivatives are set down at *d*.

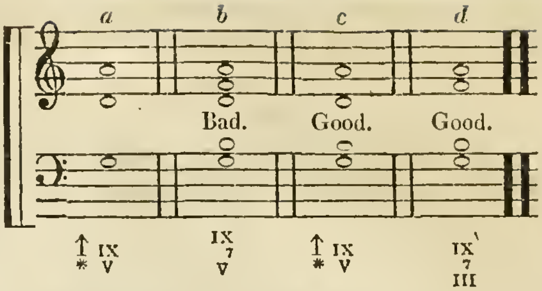
The major seventh is of one kind only, being the lesser second or diatonic semitone inverted. The chord consists of major third, perfect fifth, and major seventh; and this seventh is major third above the fifth of the chord, and perfect fifth above the third.

Let us now see a diatonic sequence of sevenths within the major scale, No. 2. In the third chord we must have the grave second of the scale as grave minor third in the chord of seventh on the sensible note; and this grave minor third must, in the next chord, rise comma, that it may be acute seventh in the next chord; that is, perfect fifth to the fifth of the key. Here, then, the minor seventh, accompanied with minor third and perfect fifth, is not truly prepared in the third of the preceding chord. Yet this procedure is not found in the least degree offensive. The two following chords are of the same kind, and both perfectly prepared; but the second of the scale must be grave, bearing its own chord of seventh.

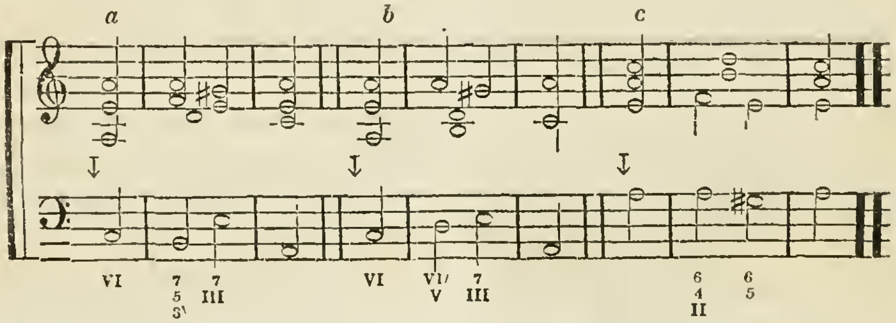


236. We have observed, Art. 155, that the dominant chord on the fifth of the scale, and that on the sensible note united, form a chord of minor seventh and major ninth on the fifth of the key. But this whole combination is inadmissible in perfect harmony. A ninth, accompanied by perfect fifth, consists of one major fifth written over another, as at *a*, and therefore can be no other than major ninth greater tone above the octave. But this ninth is false as major third above the seventh; and the interval of fifth between the fifth of the chord and the ninth is filled up with grave minor third, and this false major third of two greater tones, of which the effect is extremely bad. By making the seventh acute, this interval of fifth is truly filled up as a minor common chord; but then the lesser fifth from B to F becomes too large, consisting of two perfect minor thirds; and the whole effect is not good. This is almost the only incongruous combination into which musicians have been betrayed by the temperament of the scale.

If the minor seventh be omitted, then we have a dominant chord of major ninth, the effect of which is excellent, *c*. Or, by omitting the fifth of the dominant, (which is usually done,) we may add, the ninth true major third above the seventh; we have thus a dominant chord of major third, minor seventh, and grave major ninth, which is also very good; *d*.

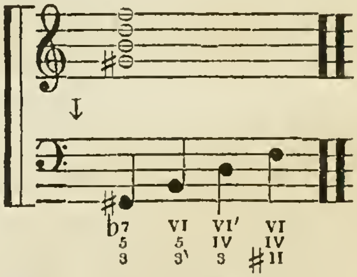


237. In the scale of the relative minor, the fourth is the grave major second of the major mode; and this fourth, added to the major common chord on the fifth of the key, gives a dominant chord of seventh exactly similar to that already described. The subdominant chord also is the very same which we have described as the chord of seventh on the sensible note of the relative major. The grave minor third to the bass of the fundamental chord well prepares that between the fifth and minor seventh of the dominant, in all the inversions of the progression, *a, b, c;* and no change is requisite here, as in the progression of the subdominant to the dominant harmony in the major mode.



238. When to the chord of lesser fifth on the sensible note of the minor mode, the diminished seventh, which is the minor sixth of the scale, is added, the chord consists of three minor thirds, that in the middle being grave. This is the only order in which these thirds can be arranged without producing a lesser fifth too large by comma. The lesser fifth to the bass consists of minor third and grave minor third; and the lesser fifth above the third of the chord consists of grave minor third and perfect minor third. The whole chord of diminished seventh thus, is composed of the two chords of imperfect fifth, described Art. 235, *a, b*. This situation of the grave third in the middle of the chord, we shall find an important matter in reviewing the enharmonic changes of this chord. The chord, with its derivatives, is figured in the example. In all the figures in this chapter, the flats or sharps have no reference to those at the clef, (as in figuring thorough bass,) but are intended to express the exact intervals as reckoned from the bass. Thus the ♭7 means diminished seventh, and ※ II, redundant second.

The union of the chord of diminished seventh with the dominant chord on the fifth of the key, makes the chord of minor seventh and minor ninth. This union implies no incongruity, as in the major ninth. The whole combination, when perfectly tuned, has a very good effect. The use of these two chords implies no change in the pitch of any note on the scale. Nor do the other chords peculiar to the minor mode, described Art. 171—174, imply the use of any pedal.



239. Thus we have perfect harmony within the major and minor relative modes, by the addition of one note to the scale, the grave second of the major mode, which is the true fourth of the minor scale. But when the modulation passes into other keys, we shall find other changes requisite. In order to explain this, we must first give the rules for tuning the whole chromatic scale perfectly true to one note, C; and then consider the imperfections which exist among the intervals of that scale.

240. The rules for tuning the remaining sounds of the scale, laid down in the Essay on Perfect Intonation, are these:

To B, (already tuned,) tune F※, and to this C※.

To E, (major third to C,) tune major third, G※, and from this last by series of perfect fifths, D※, A※, E※.

To G※ tune major third B※, and from the latter, by series of fifths, F×, C×.

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* The pedal indicated by this mark ↥ is explained below, Art. 244

To F, (already tuned,) make B♭ perfect fifth downwards.

To C, tune downwards A♭, major third; and to the latter upwards, E♭, perfect fifth.

From A♭, by series of downward fifths, tune D♭, G♭, C♭.

To A♭ tune downwards major third F♭, and to the last fifth downwards, B♭♭.

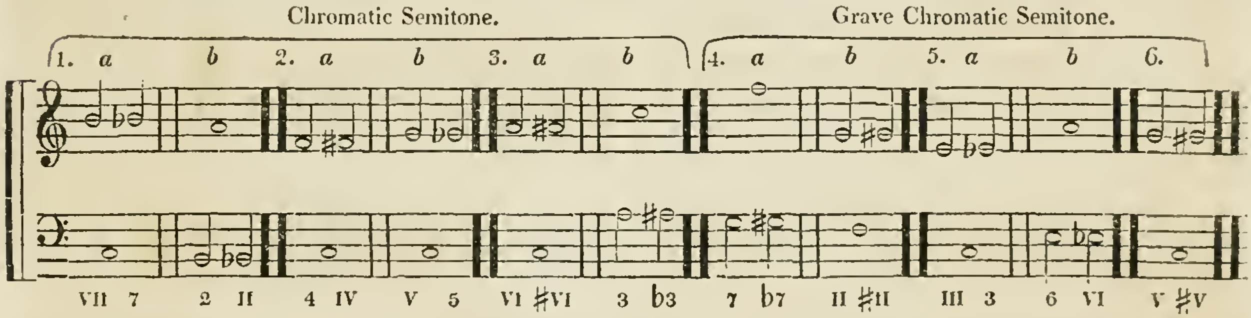
In all these tunings, the major thirds, fifths, and octaves, are to be taken quite perfect, without the least temperament.

All these sounds thus tuned, stand in true musical relation to the key-note C. But within this scale there are a great many intervals false, by the whole error of comma.

241. Let us now see the exact quantity of the intervals used in harmony, by the numbers they contain of tones major, tones minor, and semitones, which we shall denote T, t, S.

The octave contains	3 T, 2 t, 2 S
The minor second	1 S
The major seventh	3 T, 2 t, 1 S
Grave major second	1 t . . .
Acute minor seventh	3 T, 1 t, 2 S
Major second	1 T . . . . . .
Minor seventh	2 T, 2 t, 2 S
Diminished third	2 S
Redundant Sixth	3 T, 2 t . . .
Redundant Second, . . . from 1 T, and 1 t, take	1 S
Diminished seventh	2 T, 1 t, 3 S
Grave minor third	1 t, 1 S
Acute major sixth	3 T, 1 t, 1 S
Minor third	1 T . . . . 1 S
Major sixth	2 T, 2 t, 1 S
Major third	1 T, 1 t . . .
Minor sixth	2 T, 1 t, 2 S
Diminished fourth	1 T . . . 2 S
Redundant fifth	2 T, 2 t . . .
Minor or perfect fourth	1 T, 1 t, 1 S
Major or perfect fifth	2 T, 1 t, 1 S
Major fourth	2 T, 1 t . . .
Minor fifth	1 T, 1 t, 2 S

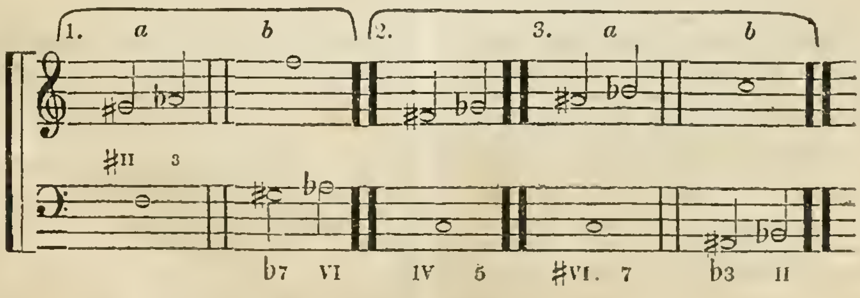
242. The smallest interval used in the above table is the diatonic semitone; but there are smaller intervals found in comparing the different intervals with each other. A chromatic semitone is the difference between a major and minor interval of the same name, or between a major and redundant interval of the same name, or between a minor and diminished interval of the same name. A chromatic semitone is hardly used in chord, except as a passing chromatic at the distance of octave. But it frequently occurs in movement from major to minor, or the reverse; and is expressed in musical notation by the character ※ or ♭. But the musical world are not generally aware that, among the intervals truly tuned, there are really two kinds of chromatic semitone, differing by comma. Thus the minor third subtracted from the major third, leaves a small interval, which is the excess of the minor tone above the diatonic semitone; it is called the grave chromatic semitone. It is very little more than the third of the greater tone. The lesser fifth, again, subtracted from the perfect fifth, leaves an interval which is the excess of the major tone above the diatonic semitone; called the chromatic semitone. It is nearly about the half of the lesser tone. These things are stated rather by way of curiosity than as of great importance to the practical musician, because no confusion arises from denoting these chromatic changes differing by comma by the same characters. By the examples 1—6, it will be seen in what changes each takes place.


Chromatic Semitone.

Grave Chromatic Semitone.

243. The enharmonic diesis, as we have already observed, is also of two kinds, differing by comma. Thus the excess of the diminished third, (or two diatonic semitones,) above the major second, (or greater tone,) is one species of diesis; called the grave diesis. It is about a tenth of the greater tone. It is rather smaller than comma. The difference between the redundant second and the perfect minor third, is the excess of two semitones above the minor tone; consequently comma greater than the former; called simply the diesis. By the examples No. 1—3, it will be seen in what enharmonic changes each diesis takes place.

Let us now see what takes place when the modulation passes into other keys.

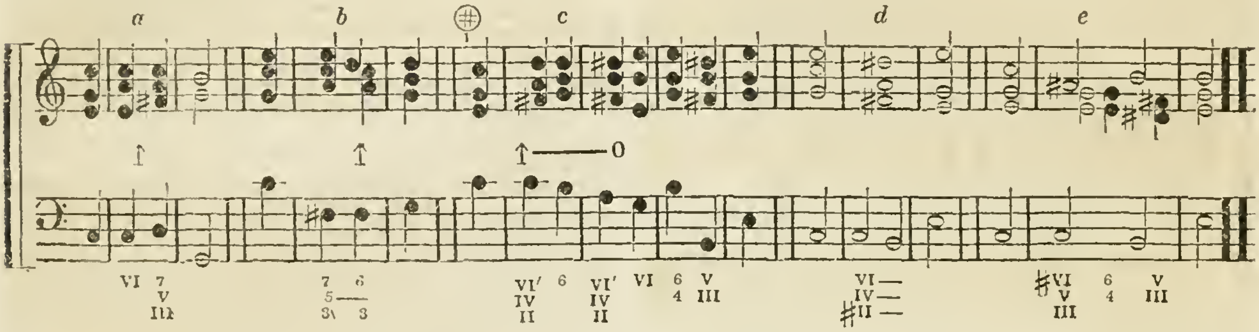

Diesis.

Grave Diesis.

244. We have seen that the sixth of the major scale is lesser tone above the fifth of the key. Hence it is easy to see what change will be required in effecting a modulation from the principal major to its fifth. The sixth of the primary key is grave second, and makes part of the subdominant harmony of the new key; but when the dominant of that new key comes, the grave second must rise comma as fifth in the dominant chord. Thus in the example *a*, the A which is major sixth to C, must rise comma to be perfect fifth to D. This is effected by another pedal called an acute pedal, and denoted by the arrow pointing upwards, ↑. We call this new sound acute, and mark it with the acute accent, A′. It

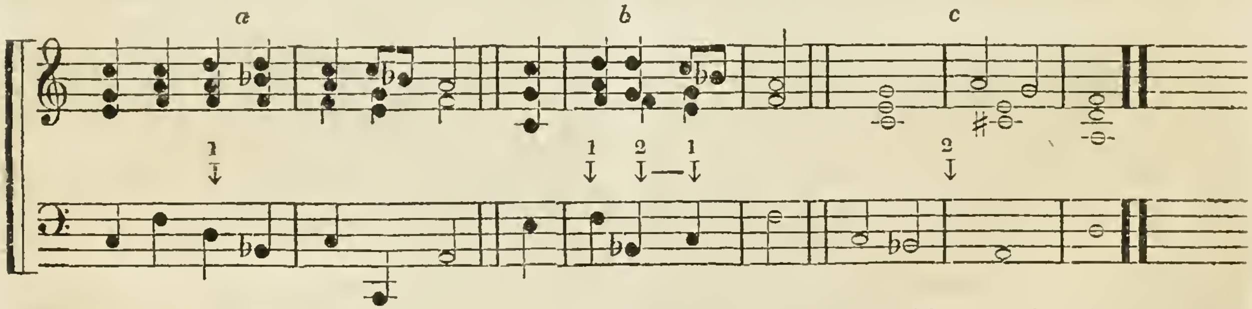
is plain that by this change the dominant seventh on D, is in all respects similar to that on G, already described. At *b*, we have the seventh on F※ the sensible note. Here we have A grave minor third to F※, as it ought to be; and when this chord is resolved as in the example on the first derivative of the dominant, we must have A′ to be minor third in that chord.

As the grave second of the major key is true fourth in the relative minor, when we go from G to E, its relative minor, the acute pedal must be released. Thus, in the example at *c*, which modulates from C first to G, and then to E, the acute pedal necessary for the dominant to G, is released when the dominant to E is struck. Here also we must have D※, not E♭ of the original scale, (Art. 228,) for which the first sharp pedal is put down at the beginning, denoted thus, $\underset{1.}{\circledast}$ It does not seem, however, very essential to mark the use of the extreme sharp or extreme flat pedals, as an intelligent performer may easily know what are required. If we pass from the key of C directly to that of E, no acute pedal is requisite at all. At *d*, we have conducted the modulation by the third derivative of the diminished seventh, resolving on the dominant; and at *e*, by the chord of superfluous sixth, to show that these modulations require no acute pedal.

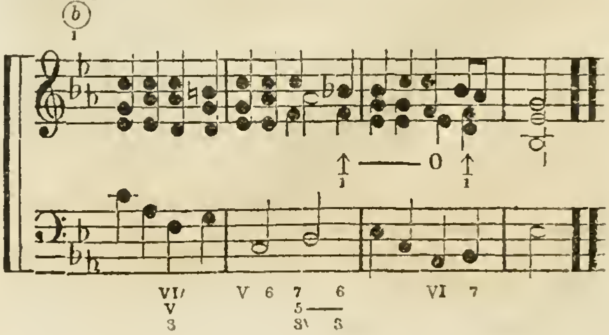


245. If we consider the scale of F, fourth to C, we find that it is the grave second of the latter, Dˋ, that is perfect major sixth to the former. But if the modulation require the grave second of the new key, we must have Gˋ also, comma flatter, then as tuned true fifth to C. This new sound is given by means of another grave pedal; and these two grave pedals are denoted thus $\overset{1}{\downarrow},\overset{2}{\downarrow}$. See the example *a*, *b*. The first grave pedal may be pressed or released without affecting the second; but the second always takes down the first along with it, if not fixed down before: when the first is fixed down, the second is pressed or released without affecting it. The reasons of this arrangement will be easily seen in the subsequent examples. When we modulate into the second of the key minor mode, it is to the grave second, or relative minor to the fourth of the key, having that fourth, and the sixth of the principal key for its third and fifth. The major seventh of this key, or major third in its leading chord, is comma graver than the C※ tuned perfect fourth below F※; and this C※ˋ may, without inconvenience, be brought in by the first grave pedal. The second grave pedal, then, which brings in the grave second of the key of F, makes the scale of its relative minor, Dˋ, correct also. See example at *e*.

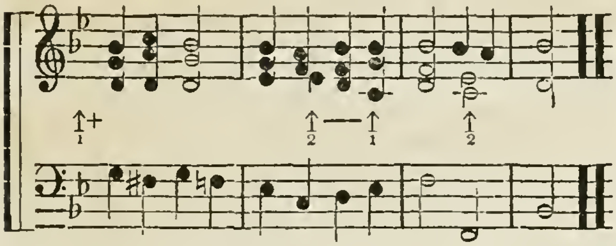
Thus, by these few additions, viz. Dˋ, Gˋ, C※ˋ, and A′, we have the whole circle of the most related keys or most natural modulation to the key of C major; and also that to the key of A minor; for the natural circle of keys is the same to both. Let us now suppose C the key note of the minor mode, and see what additions are requisite to give us a similar circle of related keys to it.



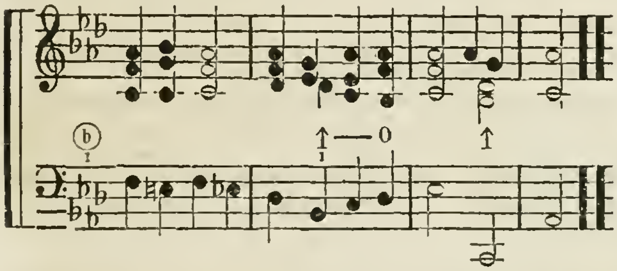
246. Now, if we would have the scale of C minor exactly similar to that of A, we shall find all the intervals tuned by the rule given, (Art. 240,) true, except B♭, which to C is minor seventh, whereas in the scale of A minor, G is acute minor seventh, being the fifth of the relative major. We must therefore have B♭′ comma sharper than B♭; which last is too grave as fifth to E♭. This B♭′ is brought in by the same pedal which brings in A′. In the relative major E♭, F, fourth of the key of C minor, is of course grave second: We must therefore have F′, major second of the scale, and perfect fifth to B♭′ its dominant. This F′, is added to the same pedal which brings in A′ and B♭′. For these two keys, we must have A♭ instead of G※, which is effected by the first flat pedal marked $\underset{1}{\textcircled{\flat}}$. The chords of these two relative keys are shown, with the use of the pedal, in the example. The chord of diminished seventh on the sensible note, or that of redundant sixth, on the minor sixth of the minor scale, require no pedal to be used.



247. In the scale of G minor, fifth to C minor, B♭′ is third, A′ is second, and F′ is acute minor seventh, all which sounds are brought into the scale by one pedal. In the scale of the relative major B♭′, (acute minor seventh to C minor,) the grave second is C; we must therefore have C′ comma sharper, for the second of the scale, and fifth in the dominant chord. This is effected by a second acute pedal, and the two are numbered thus, $\underset{1}{\uparrow},\underset{2}{\uparrow}$. In the example, the chords of these two relative keys are set down. The first acute pedal is fixed down at the beginning; signified by the cross put after the arrow. The second is pressed, when the dominant of B♭′ comes, for C′, and it is released when the subdominant chord is played, for C the grave second of the scale, sixth in that chord.



248. In the scale of F minor, we must have D♭ for the minor sixth, and this is introduced into the scale by the first flat pedal. In the relative major A♭, minor sixth of C minor, B♭ is the grave second, and B♭′ the second of the key, fifth in the dominant harmony. Hence the use of the first acute pedal is shown in the example.



249. Thus, in the circle of secondary keys belonging to the relatives C major, and A minor, and C minor, and E♭ major, we have perfect harmony by the addition of seven sounds to the scale, tuned Art. 240, three grave, viz. D‵, C♯‵ belonging to the first pedal, and G‵ belonging to the second; and four acute A′, B♭′, F′, belonging to the first pedal, and C′ belonging to the second. Now, from the key of C, this circle of modulation is the most important. If we go beyond that, it seems of small moment whether we take, for instance D♭, or C♯, or C♯‵, or whether we go to F♯ or G♭. If, then, we consider successively each principal key with a similar circle of modulation, we shall easily ascertain how many more grave or acute sounds must be added, in order to furnish perfect harmony in every modulation; and we shall, at the same time, see to what pedals they belong.

250. In the circle of keys belonging to G major and E minor, we have already seen the scale of the principals and all their secondary keys, except D major and B its relative minor. D major requires, in addition to the acute sounds, E′, as its proper second belonging to the dominant chord, which is added to the first acute pedal. B minor requires no addition; but its leading note is A♯, which is substituted for B♭ by the first sharp pedal along with D♯.

We have considered the relative principals G minor, and B♭′ major, and all the secondary keys but D minor, and F′ its relative major. The former requires no addition: in the key of F′, the grave second is G, and we require G′ as second, which is added to the second acute pedal.

251. In the circle belonging to D major and B minor we have seen the principals, and all the secondary keys except A′ major and F♯ its relative minor. The grave second to A′ is B, and we require B′ as second of the scale, which is added to the second acute pedal. We require also G♯′ as leading note; this is added to the first acute pedal. F♯ requires no addition: its leading note is E♯, substituted for F by the second sharp pedal.

In the circle of D minor and F′ major, we have considered the principal and all the secondary keys but A′ minor, and C′ its relative major. The former requires no addition. In the key of C′ the grave second is D, and we require D′ as second of the scale. This belongs to a third acute pedal marked $\underset{3}{\uparrow}$.

252. The key of A major requires, in addition to the grave sounds, F♯‵ as its relative minor: this sound is added to the first grave pedal. This minor key requires as leading note E♯‵, which is added to the first grave pedal, and B‵ as fourth of the scale, which is added to the second grave pedal. Of the secondary keys belonging to these two principals, E major and its relative minor C♯‵, require no addition. D‵ major requires E‵ as its grave major second, which belongs to a third grave pedal denoted $\overset{3}{\downarrow}$. B‵ minor requires A♯‵ as its leading note.

The relative keys of A minor and C major, with all their secondary keys, have been already considered.

253. The relative principals, E major and C♯′ minor, require no addition. The keys of B major and its relative G♯ minor, require no addition. The leading note to G♯ is F× brought into the scale by the third sharp pedal. The other secondary keys have been considered.

E minor, and its relative major G, with all their secondary keys, have been considered.

254. The keys of B major and G♯ minor, with their secondaries, require no addition. The keys of B minor and G major have been considered.

255. The principal relatives F♯ major and D♯ minor, require no addition. The leading note to the latter is C× brought in along with F×. C♯ major requires B♯′ as leading note. This is added to the first acute pedal. A♯ has no leading note. The others have been considered.

F♯ minor, and A′ major, relative principals, have been considered. E′ major requires D♯′ as its leading note, which is added to the second acute pedal, and F♯′ as second, which is added to the third acute pedal. The others require no addition.

The principals C♯′ minor and E major require no addition.

256. The relative principals F major and D‵ minor have been considered. B♭ major requires C‵ as its grave second, which is added to the second grave pedal, and E♭‵ as fourth, which is added to the first grave pedal. G‵ minor requires no addition; the rest have been considered.

F minor, and A♭ major, have been considered; none of the secondary keys require any addition.

257. The principals B♭ major, and G‵ minor, have been considered. E♭‵ requires A♭‵ as its fourth, which is added to the second grave pedal, and F‵ as its grave second, which is added to the third grave pedal. C‵ requires no addition; the others have been considered.

B♭ minor and relative D♭ major, with their secondary keys, require no addition.

258. The relative principals E♭ major and C minor, with their secondary keys, have been considered.

The principal key E♭ minor, requires G♭′ its relative major, and C♭′ its minor sixth, which both belong to the first acute pedal. G♭′ requires A♭′ and D♭′, which both belong to the second acute pedal. D♭′ major requires E♭′, which belongs to the third acute pedal. The rest require no addition.

259. The relative principals A♭ major and F minor, with their secondary keys, have been considered.

The relative principals A♭ minor and C♭ major, with their secondary keys, require no addition.

260. The principal D♭ major and B♭ minor, with their secondaries, have been considered.

D♭ minor, and F♭ major, with their secondaries, require no addition.

G♭ major, and E♭ˋ minor, with their secondaries, require no addition.

261. Collecting all these additions to the 24 notes tuned in Art. 240, under their respective pedals, they are as follows:

First grave pedal, C※ˋ Dˋ E♭ˋ E※ˋ, F※ˋ
Second grave pedal, Cˋ, Bˋ, G, A♭ˋ, A※ˋ
Third grave pedal, Eˋ, Fˋ
First acute pedal, E′, F′, G♭′, G※′, A′, B♭′, B※′, C♭′
Second acute pedal, C′, G′, B′, D♭′, D※′, A♭′
Third acute pedal, D′, F※′, E♭′

262. The reason of classing these notes in this manner, is, that all the intervals among the notes of the same pedal, are either true intervals which require no alteration, or they are such intervals as are never used in chord; so that the whole class of notes may, without inconvenience, be lowered or raised comma at once. Thus, if ever F※ be required, while Dˋ makes part of the chord, that F※ must be grave also. But the same does not hold between all the notes in the first class, and those of the second. Thus Dˋ may require either Cˋ as minor seventh, or C as acute minor seventh; D may require either C as minor seventh, or C′ as acute minor seventh. By the arrangement made, all false intervals can be corrected; and all changeable intervals can be made such as the combination requires.

The first grave pedal moves by itself, not affecting the others; the second always takes the first with it, if not previously fixed down; and the third takes both the second and first, if not previously fixed down. The same applies to the acute pedals.

263. The sounds thus added to the 24 originally tuned, Art. 240, viz. 12 grave, and 17 acute, make the whole number of sounds requisite to furnish perfect harmony in the widest circle of modulation to every principal key, amount to 53 notes within the octave. The greatness of this number, in consequence of the above classification, occasions no manner of embarrassment to the performer. This is a matter of experience; but it becomes an object of importance, on account of the great expense and the great size to which an organ of any extent comes, in consequence of these additions, to limit the number of sounds within the octave as much as possible, by leaving out the least necessary sounds.

264. In order to show what sounds can best be spared, we shall give the scales of all the keys, principal and secondary, in the tables annexed, on the opposite page. In the three first of these tables, the intervals are reckoned from each class of notes, as originally tuned, and in the three last, from the same classes acute and grave. By this means the pedals required in each key are easily seen.

265. The limitations of the scale proposed, are these, first, to leave out double sharps and flats, also F♭. These omissions occasion the loss of G※ and D※, F♭ and C♭, secondary keys. But we have still the keys of A♭, E♭, E and B. Thus though we have not a complete circle of keys to F※ major, we have one to G♭ major; and reciprocally, though we have not G♭ minor with its circle, we have F※ minor, with its circle. The greatest loss is in the keys of E and B, in whose modulations we must for G※, and D※, the third of the key, substitute A♭, and E♭. Yet even in G※, and D※, a species of close may be effected, though not the best, for want of the leading note. By these omissions the third sharp and the third flat pedals are spared, and the original scale is reduced to twenty notes in the octave.

In the acute and grave sounds it is proposed to leave out the third pedal of each, also the acute sounds belonging to the second pedal D♭′ D※′ A♭′. By these omissions, the scale of the instrument contains within the octave 41 sounds, which furnishes a very great range of modulation, all perfectly in tune.*

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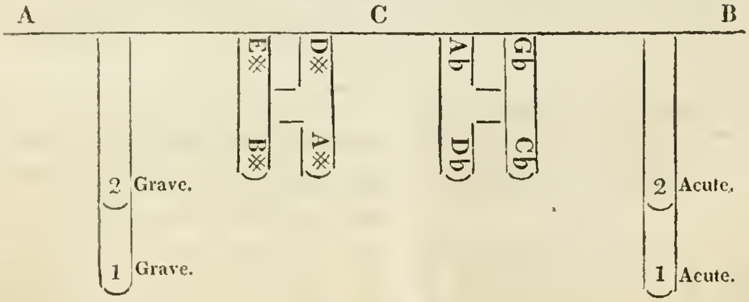
* The largest instrument hitherto made on this principle, is that in the Scottish church at Calcutta, built by Flight and Robson of London, under the direction of Mr. Liston, the inventor. Its scale comprehends 39 notes within the octave, A♭ˋ, and A※ˋ, being omitted. It was found, however, that these two sounds were pretty often desiderated. This organ contains two open diapasons, one metal and one of mahogany, and one stopt diapason mahogany, all down to GG; principal, fifteenth, and a four rank cornet and sesquialter throughout. The whole being tuned quite perfect, the effect is admirable; that of the compound stops, especially, is the richest and purest imaginable. A very short practice is found sufficient to make the performer familiar with the use of the pedals. This arises from the orderly manner in which they are disposed. The extreme sharp and extreme flat pedals, are different in form from the acute and grave pedals, as shown in this scheme.



The line AB represents the front of the instrument. The extreme flat pedals are placed towards the right, the first nearest the centre C, and the second more remote. They are so placed, because the sounds which they introduce are sharper than those of the original scale for which they are to be substituted. The extreme sharp pedals are placed towards the left of the centre, after the same manner; the sounds which they bring in being flatter than those of the original scale. The first of each moves freely by itself; but the second takes the first along with it, by means of its wing, which passes under the second. The acute pedals, again, which are placed towards the right, just beyond the extreme flat pedals, lie one over the other; as do also the grave pedals, which are placed toward the left, just beyond the extreme sharp pedals. Thus the whole stand so distinct, that no confusion can arise among them. So little embarrassment, indeed, do the performers experience in their use, that they find no difficulty in managing at the same time a swell pedal, which is in the centre of the whole, and a shifting movement to bring on and take off the compound stops.

TABLE I.

VII	D♯	E	G♯	A	F	F×	B♭
7′	D	E♭	G	A♭	F♭	F♯	B♭♭
VI	C♯‵	D‵	F♯‵	G	E♭‵	E♯‵	A♭‵
6	C	D♭	F	G♭		E	
V	B	C	E	F	D♭	D♯	G♭
4	A	B♭	D‵	E♭‵	C♭	C♯‵	F♭‵
III	G♯	A	C♯‵	D‵	B♭	B♯	E♭‵
3	G	A♭	C	D♭	B♭♭	B	
II	F♯	G	B	C	A♭	A♯	D♭
II‵	F♯‵	G‵	B‵	C‵	A♭‵	A♯‵	♭‵
	E	F	A	B♭	G♭	G♯	C♭‵
	Principal Keys, Major and Minor.				Principal Major.	Secondary Keys.	

TABLE II.

VII	B	F♯	G	A♯	C	C×
7′	B♭′	F′	G♭′	A′	C♭′	C♯
VI	A	E	F	G♯	B♭	B♯
6	A♭	E♭	F♭	G	B♭♭	B
V	G	D	E♭	F♯	A♭	A♯
4	F	C	D♭	E	G♭	G♯
III	E	B	C	D♯	F	F×
3	E♭	B♭′	C♭′	D	F♭	F♯
II	D	A′	B♭′	C♯	E♭	E♯
II‵	D‵	A	B♭	C♯‵	E♭‵	E♯‵
	C	G	A♭	B	D♭	D♯
	Principal Keys, Major and Minor.				Principal Minor.	Secondary.

TABLE III.

VII	C♯	D	E♯	B♯′	E♭
7′	C′	D♭′	E′	B′	
VI	B	C	D♯	A♯	D♭
6	B♭′	C♭′	D	A′	
V	A′	B♭′	C♯	G♯′	C♭′
4	G	A♭	B	F♯	B♭♭
III	F♯	G	A♯	E♯	A♭
3	F′	G♭′	A′	E′	
II	E′	F′	G♯′	D♯′	G♭′
II‵	E	F	G♯	D♯	G♭
	D	E♭	F♯	C♯	F♭
	Principal Major and Minor.		Principal Minor.	Secondary.	

TABLE IV.

VII	D♯′	E′	F′	G♯′	A	B♭′
7′	D′			G′	A♭′	
VI	C♯	D	E♭	F♯	G	A♭
6	C′			F′	G♭′	
V	B′	C′	D♭′	E′	F′	G♭′
4	A′	B♭′	C♭′	D	E♭	F♭
III	G♯′	A′	B♭′	C♯	D	E♭
3	G′			C′	D♭′	
II	F♯′	G′	A♭′	B′	C′	D♭′
II‵	F♯	G	A♭	B	C	D♭
	E′	F′	G♭′	A′	B♭′	C♭′

Secondary Keys.

TABLE V.

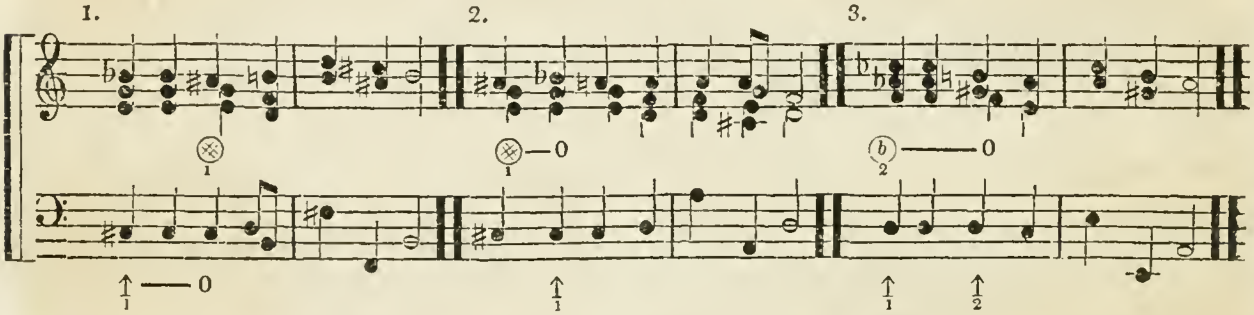
VII	B′	C′	B‵	F♯‵	A♯‵	G‵
7′			B♭	F	A	G♭
VI	A′	B♭′				
6			A♭‵	E♭‵	G‵	F♭
V	G′	A♭′	G‵	D‵	F♯‵	E♭‵
4	F′	G♭′	F‵	C‵	E‵	D♭
III	E′	F′				C‵
3			E♭‵	B♭	D‵	C♭
II	D′	E♭′	D‵	A	C♯‵	B♭
II‵	D	E♭				
	C′	D♭′	C‵	G‵	B‵	A♭‵
	Major.	Major.	Minor.	Minor.	Minor.	Minor.

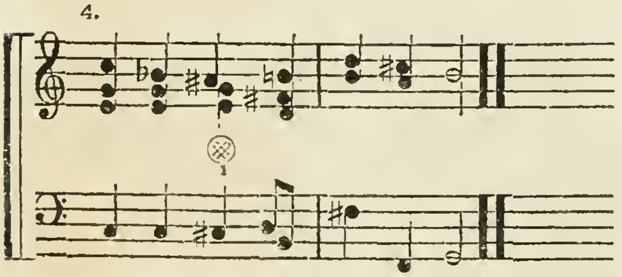
TABLE VI.

VII	B♯	C♯	C♯‵	D‵
7′	B	E	C	D♭
VI			B‵	C‵
6	A	D‵	B♭	C♭
V	G♯	C♯	A	B♭
4	F♯‵	B′	G‵	A♭‵
III			F♯‵	G‵
3	E	A	F	G♭
II	D♯	G♯	E	F
II‵			E‵	F‵
	C♯‵	F♯‵	D‵	E♭‵
	Principal Minor.	Minor.	Major and Minor.	

266. It remains to give a short exposition of enharmonic changes, in the chord of diminished seventh, when the change is real, as it may be effected on this instrument. The real enharmonic change of one or two parts of the chord, as we have observed, Art. 164, has a very agreeable effect. Besides the change of the diesis, there is always another alteration of *comma* arising from the place of the grave minor third, which is in the middle of the fundamental chord of diminished seventh, and differently situated in the several inversions. One or two examples will best illustrate this matter. No. 1 shows the chord of diminished seventh to C※; and to have the chord in its true form, both the E and B♭ must be made acute, which is effected by the first acute pedal. Now when, by the enharmonic change of B♭ to A※, the chord becomes the first derivative of the diminished seventh to that note, the minor third next the bass must be grave; see the example, Art. 238; when, therefore, the performer presses the first sharp pedal for A※, he at the same time releases the first acute pedal, so that the acute E falls comma, and becomes true interval of major 4th below A※. And the ear perfectly approves of both these changes. It is evident that the directly opposite change will take place when the progression is reversed, as in No. 2; and that similar changes will be required in all the inversions of these progressions. When two of the parts are changed enharmonically, there will be no change by comma requisite in the remaining parts, but the use of an acute or grave pedal may be requisite. Thus, in No. 3, we have the diminished seventh to D, and in order to have the chord in its true form, both F and C♭ must be acute, which is effected by the first acute pedal; yet when, by the enharmonic change of the C♭ and A♭, the chord becomes the second inversion of the diminished seventh to G※, we must have the second acute pedal for B′, though both D and F remain as before the enharmonic change. The same thing will take place in all the inversions of the progression: And in reversing the progression, the reverse use of the pedals will be requisite, which it is unnecessary to exemplify. This double enharmonic change is still very agreeable. When three parts are changed, the effect is less agreeable, and the change of the whole chord has not a good effect.

But in all progressions of the chord of diminished seventh, the enharmonic change may always be entirely avoided by the manner of taking the first diminished seventh, whether fundamental or inverted. Thus, if we suppose the modulation in No. 1, to have proceeded from the key of C, as in No. 4, it is plain that, by taking A※ instead of B♭ in the second chord, the enharmonic change may be entirely avoided. Thus the musician has it in his power to make such changes more or less striking, or highly seasoned, as he may choose. But we must refer our reader for a more complete account of this matter, to *Liston's Essay on Perfect Intonation*, of whose doctrine we have in the preceding pages given a short abstract.*





267. From the account of the true diatonic scale given in Art. 229, it is easy to understand the necessity of *tempering*, that is, tuning a little false those keyed instruments which have fixed scales, whether the scale comprehend 24 sounds, or only 12, as is usual. It appears that, if from C we tune G D A E, by ascending fifths and descending fourths, all perfectly true, the last of the series E is too sharp by comma, as major third to C. Now, it is plain that, if instead of taking the series of fifths perfect, we should make each a little too flat, the whole error in the pitch of E will be diminished. As there are four steps in the process, if we take from each fifth ¼th of comma, the correction will exactly compensate; the error will disappear, and the major third will be perfect. If from this E, we proceed by a second series of similarly tempered fifths, to tune B, F※, C※, G※, this last will be perfect major third to E. After the same manner returning to C, if we tune F fifth below it too sharp, so that C may be ¼ of comma too flat as fifth to F, and thence by similarly tempered fifths tune B♭ and E♭, we shall have tuned the scale by what is called the vulgar temperament. This is the temperament generally practised on the organ, and is recommended as the best for that instrument by the ingenious organ-builder, Mr. Flight, in a little work which lies before us. In consequence of this arrangement, every major third and minor sixth is perfect, in scales that have not more than three sharps or two flats at the clef. Beyond these limits, every major third or minor sixth is extremely harsh, being altered by the whole diesis. The minor thirds within the same limits, are too flat, and the major sixths too sharp by ¼th comma; and beyond these limits, they are still farther altered by the whole diesis. All the fifths are too flat by ¼th comma, and all the fourths as much too sharp, except where G※ stands for A♭, which makes an extremely bad interval with E♭. The intervals altered by diesis are called wolf intervals; and that between G※ and E♭ is called the great wolf.

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* As the Editor has been indebted to the Rev. Henry Liston, of Ecclesmachan, for this valuable article on Music, it may be proper to state, for the information of those who are not personally acquainted with that gentleman, that the different musical articles in this work, in which his "Essay on Perfect Intonation" are spoken of with such high approbation, were written by John Farey, Esq. Sen.—Editor.

On the pianoforte the most prevalent practice is to divide the scale of the instrument as nearly as possible into 12 equal semitones. For this purpose, the fifths are all kept finer than in the above temperament; being flattened only about $\frac{1}{11}$th of comma. By this means the wolf intervals disappear; but this is brought about by making the thirds and sixths major and minor so harsh, that they could not be tolerated were the sounds held out as in the organ. Custom, however, has reconciled the ears of the musical world to these intervals; and the convenience of having every key equally good, though none very good, recommends this method of tuning to general adoption.

268. Of Musical Instruments, we shall treat, in subsequent articles of this work, viz. Organ, under which we shall class the pianoforte and other keyed instruments: Stringed Instruments not played with the bow: Violins, under which we shall class the tribe of perfect instruments played with the bow, and without frets; and lastly, Wind Instruments. In the mean time, we give, in Plate CCCCIV.* a table of the compass of voices and instruments, showing the place which each occupies in the scale.

On the subject of Music, the student may consult with advantage the following works. *Methode Elementaire de Composition*, &c. par J. Georg. Albrechtsberger; traduit de l'Allemand; par M. A. Choron. *A Musical Grammar*, by Dr. Callcott. *Traité D'Harmonie*, par Catel, *adopté par le Conservatoir de Musique à Paris. Principes de Composition des Ecoles d'Italie*, par Alexandre Choron. An excellent work, in which the compiler gives the theoretical treatises of Marpurg, conjoined with the admirable models of Martini, Sala, and other Italian masters. *An Essay towards a Rational System of Music*, by John Holden. J. Ph. Kirnberger, *Die Kunste des reinen Satzes*, &c. The art of composition on fixed principles, &c. Id. *Die wahren grundsætze*, &c. Principles of Harmony. Id. *Grundsætze des general basses*, &c. Principles of Continued Bass, to serve as the elements of composition. *A New theory of Musical harmony*, &c. by A. F. Ch. Kollmann. Fred. William Marpurg *Abhandlung von der fuge, &c.* A treatise of Fugue, &c. Id. *Handbuch bey dem General Bass*, &c. A Manual of continued bass and of composition. These excellent works of Marpurg are given entire by Choron in his *Principes*, &c. Il Padre Giambattista Martini, *Saggio fondamentale pratico di Contrappunto*. Il Padre Luigi Ant. Sabbatini, *La vera idea delle musicale numeriche segnature*. Id. *Trattato sopra le Fughe Musicale. An Introduction to Harmony*, by William Shield. The *Supplement* to the same. In setting down this list, we have been careful rather to direct the student to such works as will be useful to him, than to give an extensive catalogue.

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MUSKET. See Gunmaking.

MUSKINGUM, a river of the United States, in the state of Ohio. This stream is formed by two branches. Whitewoman's and Tuscarawas rivers. The former rises by a number of sources in Richland, Knox, and Wayne counties, interlocking with the head waters of Sciota and Sandusky, entering Ohio, and Vermillion and Black rivers, flowing into Lake Erie, passing through Coshocton county, join the Tuscarawas river at the town of Coshocton. The entire comparative length of Whitewoman's river, from its mouth to the extreme source of Armstrong's creek in Richland county, is about seventy miles, draining one of the most fertile tracts of land in the United States.

The Tuscarawas river has its sources in Harrison, Columbiana, Stark, Portage, Medina, and Wayne counties, interlocking with those of Rocky river and Cayahoga, flowing into Lake Erie, and Great Beaver entering Ohio. The Tuscarawas river is about ninety miles in length from the town of Coshocton, to its extreme source in Medina county.

Below the junction of Whitewoman's and Tuscarawas rivers, the united waters take the name of Muskingum, which flowing south, eight miles, through Coshocton, receives from the east Hill's creek on the border of Muskingum county, and continuing south a little west, twenty-three miles to Zanesville, receives Licking creek from the west. After being precipitated over a fall of about seven feet, at Zanesville, the Muskingum turns south-east by south, and flowing sixty miles, enters the Ohio river at Marietta. Between Zanesville and its efflux into Ohio, the Muskingum river passes through Muskingum, Morgan, and Washington counties. This river is navigable with large batteaux to the falls below Zanesville; for boats of considerable size to Coshocton; and for small craft nearly to the source of the Tuscarawas. A canal has been projected to unite the latter stream to the head waters of Cayahoga river, and by this channel unite the Ohio river to Lake Erie. A canal, with locks, is already cut around the falls at Zanesville, opening a navigation into the centre of the state of Ohio.

The country drained by the sources of the Muskingum is generally level, but becomes more hilly approaching the Ohio river. In point of climate this river flows from North Lat. 41° 07′ to North Lat. 39° 28′. The area it drains nearly circular, about 7850 square miles.

Darby.

MUSSELBURGH, a sea-port town of Scotland, in the county of Mid-Lothian, is situated on the southern coast of the Frith of Forth, at the mouth of the river Esk. The town of Musselburgh, properly so called, consists chiefly of one street, wide, and well paved, and containing many good houses, with the prison and town-house situated near the middle of it. The suburb of Fisherrow and Market Gate is separated from the town by the Esk, which is crossed by three bridges, one for foot passengers, made of wood, another which is very old, and an elegant and substantial new bridge designed by Mr. Rennie. The village of Inveresk, which may be considered as another suburb, is delightfully situated on high ground to the south of Musselburgh, and contains many elegant villas. The church of Inveresk, which has been lately rebuilt, is a large structure, with a lofty spire, and forms a fine object at a distance. Besides this church there is a Relief church, a Burgher meeting-house, a Haldanite chapel, and an Anabaptist meeting-house. Pinkie house, formerly the residence of the Setons, earls of Dunfermline, stands at the south end of the principal street, and is now the property of Sir John Hope. On the site of the ancient chapel of Loretto, a cell to the abbey of Dunfermline, there has been erected a good modern villa. One of the cells, covered by a moat, still exists in the garden. There is here an excellent grammar school, which has long been in great repute. The principal manufactures in Musselburgh are, those of salt, leather, pottery, starch, haircloth, and nets for the herring fishery. Sheep skins were also dressed into what is called roan. The downs or links of Musselburgh, which lie between the town and the sea, have been lately converted into a race course for the Edinburgh races, which were first held there in October 1816. The earl of Mar is said to have given Musselburgh its first charter in 1340; but the oldest charter it possesses bears the date of 1562, and was granted by the commendator of Dunfermline. Musselburgh was erected into a royal burgh in 1632; but its charter was reduced the same year, through the influence of the magistrates of Edinburgh. King James VI. gave the superiority of the town to the earl of Lauderdale, in whose family it remained till 1709, when it was bought by the duchess of Buccleuch. It now belongs to the duke of Buccleuch as lord of the regality. The town is governed by a town council, of 18 members, 8 of whom are elected from Fisherrow. In the neighbourhood of Pinkie the Scots were defeated by the English with great slaughter in 1547; and on Carberry hill the forces of queen Mary and Bothwell were dispersed by the confederate army, and the queen taken prisoner in 1567.

The population of the parish, in 1811, was 1316 houses and 6393 inhabitants, and that of the burgh 5500.

MYCENÆ, a town of Greece, in the ancient kingdom of Argos, received its name from Mycene, a nymph of Laconia, and was situated about 50 stadia from Argos. Though once the capital of a kingdom, its site was almost unknown in the time of Strabo. An account of its ruins will be found in Clarke's *Travels*, vol. iii. p. 706.

MYRRH, Gum, is the name of a gum resin which issues spontaneously, or after incision, from a tree which grows in Arabia and Abyssinia. Some account of it will be found in our article Chemistry, and in Materia Medica.

The quantities of myrrh imported in 1806, 1807, and 1808, were about 127 cwt. worth about 3452*l* averaging nearly 20*l*. per cwt. See *Phil. Trans*. vol. lxv. p. 408, and Milburn's *Oriental Commerce*, vol. i. p. 107.

MYSORE, a large province in the south of India, situated between the 11th and 15th degrees of north latitude, extends above 210 miles in length, and 140 in average breadth. It is inclosed by the Eastern and Western Ghauts, and consists of a high table-land, nearly 3000 feet above the level of the sea. It is entered by several passes; but all the practicable roads unite in one of these, namely, the Palicaud pass, which renders the defence of the country more easy. There are many lofty hills in the province, from which most of the rivers which water the south of India take their rise. The principal of these rivers are, the Toombuddra, the Vedawati, the Bhadri, the Arkanati, the Penar, the Palar, the Panaur, and the Cavery, which last is the only one that attains to any magnitude while within the bounds of the province. The climate in this elevated region is more temperate and healthy than in any other tract of the same extent within the tropics. The monsoons, which, at different seasons, deluge the coasts of Malabar and Coromandel, have their force broken by the Ghauts or mountains which surround the province; and on either side extend into the interior parts in frequent showers, which, though sometimes heavy, are seldom of long continuance, and which preserve the temperature of the climate, as well as promote the freshness of vegetation, throughout the year. The province abounds in iron-ore, which is worked by the natives, but in a very slovenly manner, and which yields, under their management, above 47 per cent of malleable iron, in a very impure state.

The family of the Rajah of Mysore is supposed to have had its origin from the Yadava tribe, which, at a remote period, had its residence in the Guzerat peninsula. The first sovereign of the country in record was Cham Raj, who ascended the throne, A. D. 1507, but who was only the governor of a small district. Succeeding princes added new territories to the original principality; but in the reign of Canty Raj, who ascended the throne in 1704, began the influence of the delawais, or ministers of state, which ever after kept the rajahs as mere pageants of authority. In 1749, Hyder Ali Khan, a Mahometan soldier, entered the service of the Mysore army at 27 years of age, and, though unable to read or write, speedily rose to a distinguished rank. In 1760, he banished the Delawai Nunseraj, who had been his patron, and usurped the sovereignty, leaving to the reigning rajah the nominal supremacy. He made great additions to his dominions; and in 1780 invaded the lower Carnatic, which he laid waste in every direction, and extended his ravages to the gates of Madras. His progress was arrested by the exertions of Mr. Hastings and Sir Eyre Coote; but, being powerfully assisted by the French, he carried on an indecisive war till his death on the 9th December, 1782, when he was succeeded by his son Tippoo, who had already acquired the reputation of a great warrior. This prince prosecuted the war against the British till he was deprived of the co-operation of the French by the peace of 1784, when he concluded a treaty on honourable terms. He continued, however, to harass his neighbours on every occasion; and in 1790 made an unprovoked attack upon the Rajah of Travancore, who applied to the British government for the assistance which they were bound by treaty to render him. A war was in consequence begun, which terminated in March, 1792, by a peace which Lord Cornwallis compelled Tippoo to conclude under the walls of Seringapatam, and which deprived him of one half of his dominions. In consequence of renewed attempts on his part for regaining his lost power, a second war broke out, which was brought to a conclusion on the 4th May, 1799, by the storming of Seringapatam by the British army under General Harris, and the death of Tippoo himself, who fell in the attack. With him ended the Mahommedan dynasty of Mysore, after lasting only 38 years. The British government immediately raised to the throne a legitimate descendant of the Mysore family, which had been superseded by that of Hyder; and stipulated by treaty that the Company should maintain a military force in Mysore, for its defence against all external enemies, and that the Rajah should pay an annual subsidy for its support. The inhabitants of Mysore have, since that period, remained undisturbed by foreign invasion or internal dissention; and the general prosperity of the country has been greatly promoted.

The dominions of the Mysore rajah are at present divided into three great districts, called the Patana, the Nagara, and the Chatrakae subayenas. The first of these is by far the largest, containing 9 districts, and is under the immediate inspection of the dewan or prime minister. The two last, which have been acquired since their connexion with the British, and which contain, the one 13, and the other 19 districts, are each superintended by a soubahdar. Each district is managed by an amildar, who is an officer of police, justice, and revenue, but with limited authority. Under these are a number of accountants called parputties, and under them the villages are managed by hereditary officers, called gaudes and shanabogas, the former representing the amildar, and the latter the village accountant.

The province of Mysore appears to have been formerly in a much higher state of cultivation than it is at present, but it is rapidly recovering from the depression in respect of agriculture and commerce which it had experienced. Considerable attention is paid by the farmer to the manuring of the soil; but the utmost degree of improvement of which they have any idea is, to make the land capable of bearing rice crops. It is a commonly received opinion among them, that when there is an adequate supply of water, the ground is best preserved in a good state by successive crops of rice; but they rarely take two crops of that grain from the same field in one year. In some parts of Mysore, land of the first quality will produce 49 bushels, of the second quality, 42, and of the third quality, 24. The farmers seldom have long leases; but the tenant is rarely moved as long as he pays the rent. When he runs away for arrears of rent or oppressive treatment, and goes into the district of another amildar, it is not customary in any native government to give him up; which proves a considerable check on arbitrary conduct on the part of the amildars, who would in that case soon be deserted by their peasantry. Besides rice, and several other grains, the country yields crops of raggy, (*cynosurus corocanus*,) which is the most important of all the crops raised on the dry fields, and supplies the lower ranks with their ordinary food. The sugar cane is cultivated in soils of black clay, and the ricinus palma Christi, which produces abundance of castor oil. In low grounds, the betel leaf tree thrives well; and about Colar, the poppy is plentifully cultivated, both for making opium and for the seed, which is much used in sweet cakes by the higher classes. Tobacco is not generally raised, and what is produced in the province is accounted of an inferior quality to that of the lower districts in India; but the cocoa nut palm begins to bear at the age of 7 or 8 years, and lives to a great age. The grass roots are of great length, and sprout at every joint, so that they are difficult to be removed in tillage; and the ploughs are so extremely imperfect, (being without coulter or mould-board,) that the fields are usually in a very foul state.

The cattle chiefly reared in the vicinity of Seringapatam are, cows, sheep, buffaloes, and the long-legged goat. The sheep are red, black, and white. Swine were once very common in the country, but Tippoo succeeded in banishing them from the neighbourhood of the capital. The native breed of horses is a small, ill-shaped, and vicious poney; and, above the Ghauts, asses are very much used; but these animals also are of a small size, and no care is taken to improve the breed. The Mysore country is thinly inhabited in comparison with Bengal. The adjacent provinces under the British government, and many districts, formerly well peopled, were almost completely desolated by the incessant wars and calamities previous to 1799. But, as soon as the new administration was established by the British government, all balances of revenue were remitted, and the ancient Hindoo state of assessment restored, and various other means employed to encourage the oppressed inhabitants. In 1804, the gross revenue of the Mysore rajah's state was 2,581,550 pagodas, and the number of inhabitants 2,171,754, of which not one thirtieth part was of the Mahommedan religion. As Mysore had submitted to the Mahommedan yoke at a very recent period, compared with the rest of Hindostan, its inhabitants retain the Hindoo manners and customs in considerable purity. In the country round Seringapatam, the people are divided into what are called the right and left hand sides, the first comprehending 9 castes, and the last 18. The Whallia caste are counted the lowest in this province, yet they are very desirous of keeping up the purity of the breed. Every where in Mysore the palanquin bearers are of Telinga origin. The dress of the females in most parts of the provinces is very becoming; they have in general fine forms. Owing to the custom of polygamy few of them are unmarried. Except a certain caste, the practice of widows burning alive with their dead husbands is becoming obsolete. In the villages near Seringapatam, a great part of the peasantry eat pork; but, though the river Cavery abounds in fish, the natives are not fond of them as food. The person who receives charity is, in this country, always regarded as of higher rank than the donor; but it is understood that the receiver is one who has devoted himself to a religious life, and is asking alms in the name of God. In their plans of revenge, they sometimes bring calamity upon the whole village to which they belong, namely, by killing a jack-ass in the street, which instantly causes the whole inhabitants to desert the place. It is accounted criminal to kill the monkeys or squirrels, which are very numerous in the country, and very destructive. The washerman of every village washes all the farmers' clothes, and, according to the number of the family, receives a certain proportion of the crop as his wages. When a new village is founded, it is customary to erect a large stone near, or in the place, as representing the tutelary divinity. When the women have borne several children, they often go to the temple and cut off one or two fingers of the right hand, to secure their infants from the wrath of the idol. See Hamilton's *East India Gazetteer*; Dr. Francis Buchanan's *Travels*; Lord Valentia's *Travels in India*; and General Dirom's *Narrative of Campaigns in Mysore*. (*q*)

MYTHOLOGY, (from Μυϑος, *a fable*, and Λογος, *a discourse*,) is a term which is generally applied to that branch of historical science, which treats of those early traditions upon which the Pagan worship of the ancient nations of the world was founded.

This is a subject which is involved in much intricacy. From the great length of time, indeed, which has elapsed since the origin of Pagan worship, and the obscurity in which the early history of all nations is shrouded, it is extremely difficult to trace the origin of their various religious rites, even with all the assistance that can be derived from a knowledge of what may be called the primitive languages, and the utmost etymological acumen. One point, however, in the midst of this general obscurity, appears to have been pretty satisfactorily made out, by the laborious researches of those learned and ingenious men, who have devoted their attention to this subject; viz. That the mythology of the most ancient Pagan nations, how much soever it may have been corrupted in subsequent times, had an obvious reference to the traditions which had been preserved respecting the antediluvian period of the world, to the deluge itself, and to the Sabian idolatry, which seems to have been one of the earliest corruptions of the true religion.

Long after the dispersion of mankind, and the confusion of tongues, the memory of the deluge, and of the Noachites, who survived that divine judgment, was still preserved by their posterity. In the course of time, these arkites, the common parents of all the subsequent races of mankind, came to be considered as divinities; and when, at length, the tradition became more and more obscure, their names and attributes were transferred to, or rather associated with, some more sensible objects of worship. Of these, the great luminary, the sun, was the most obvious; then the moon, and the rest of the host of heaven. This mixture of the arkite and Sabian worship appears to have constituted the essential characteristic of the primitive Pagan idolatry. It is but imperfectly preserved in the fragments still extant of the mythological and cosmological writings of Sanconiathon, Berosus, and other early authors; but enough remains, we think, to satisfy us respecting the sources from which it was derived, and to justify us in referring it to the one principle which we have just stated. This idolatry, originally prevalent in the east, gradually spread from thence over nearly the whole of the globe, having been carried to the remotest quarters by the migratory tribes who went in search of new settlements; and, however diversified by the peculiar genius and character of the various nations, it still continued to exhibit manifest indications of the original fountain from which it had flowed.

The symbolical imagery, however, which was so very much in use among the ancients, and which will be found to pervade the whole of their heterogeneous mythology, soon came to supersede almost entirely the remembrance of the things signified. So it was, at least, among the vulgar. The mysterious doctrines, indeed, which were thus represented in their symbolical worship, were for a time carefully preserved by the priesthood; but even these sacred depositaries themselves seem to have gradually lost sight of the application of the symbols which they employed. Hence, amidst the multiplicity of characters, and variety of symbols, it is extremely difficult to trace the original derivation of the pagan deities, or the meaning of the idolatrous worship which was paid to them.

The mythology of Greece, says Mr. Bryant, is a vast assemblage of obscure traditions, which have been transmitted from the earliest times. They were described in hieroglyphics, and have been veiled in allegory; and the same history is often renewed under a different system and arrangement. A great part of this intelligence has been derived to us from the poets; by which means it has been rendered still more extravagant and strange. We find the whole, like a grotesque picture, blazoned high, and glaring with colours, and filled with groups of fantastic imagery, such as we see upon an Indian screen, where the eye is painfully amused, but where little can be obtained which is satisfactory and of service. The same author observes, that the Grecians were so prepossessed with a notion of their own excellence and antiquity, that they supposed every ancient tradition to have proceeded from themselves. Hence their mythology is founded upon the grossest mistakes; as all extraneous history, and every foreign term, is supposed by them to have been of Grecian original. For this reason their etymologies are always fanciful; and it is not unusual for them to deduce the origin of places, founded long before they themselves were known as a nation, from some arbitrary analogy with certain terms in their own language. The native Helladians, indeed, were very limited in their knowledge. They had taken in the gross whatever was handed down by tradition, without making any farther inquiry; and they assumed to themselves every history which was imported. They, moreover, held every nation but their own as barbarous; so that their insufferable vanity rendered it impossible for them to make any great advances in historical knowledge.

The Helladians were colonies of the race called Amonian, or descendants of Ham, the son of Noah, and came from Egypt and Syria, but originally from Babylonia. They came under various titles, all taken from the religion which they professed. As soon as the Amonians were settled and incorporated with the natives, a long interval of darkness ensued. The very union produced a new language; at least, the ancient Amonian became by degrees so modified and changed, that the terms of science and worship were no longer understood. Hence the titles of their gods were misapplied, and the whole of their theology grew more and more corrupted, so that very few traces of the original were to be discovered. In short, almost every term was misconstrued and abused. They therefore devoted themselves to an idle mythology; and there was nothing so contradictory and absurd, but was greedily admitted, if sanctified by tradition. The same idle zeal induced them to tincture the accounts which they gave of other countries with the same predominant vanity, and made them attribute to their fathers the merit of many great performances to which they were utterly strangers, and supposed them to have founded cities in various parts of the world, where the name of Greece could not have been known—cities which were in being before Greece was a state. Wherever they got footing, or even a transient acquaintance, they, in their descriptions, accommodated every thing to their own fine conceptions, and expressed all terms according to their own mode of writing and pronunciation, in order that appearances might be in their favour.

The whole mythology of the Greeks,—their idolatrous rites, as well as their gods and heroes,—was originally imported from the East. Length of time had greatly impaired their true history, and their prejudices would not suffer them to retrieve it. At last, the obscurity was such, that they, in a great measure, lost sight of their origin, and were involved in mystery and fable. In order, therefore, to arrive at just conclusions respecting the origin of the ancient Pagan superstitions, we must have recourse to authors who derive their information from other and more authentic sources; such as Diodorus, Strabo, Pausanias, the fathers Theophilus, Tatianus, Athenagoras, Clemens, Origen, Eusebius, Theodoritus, Syncellus, Eustathius, and the compiler of the Chronicon Paschae; as also, Lucian of Samosata, Cyril of Jerusalem, Porphyry of Syria, Proclus of Lysia, Philo of Biblus, and others. These writers, although posterior to the Greek literature, had access to better information upon this subject than any native Helladian. They had the archives of ancient temples to which they could apply; and had traditions more genuine than ever reached Greece. They appeal to authors far prior to any Helladians; and their works are crowded with extracts from the most curious and most ancient histories.

The ancient history and mythology of Greece was partly transmitted by the common tradition of the natives, and partly preserved in those original Doric hymns, which were universally sung in their Prytaneia and temples. These were in the ancient Amonian language, and said to have been introduced by Pagasus, Agyieus, and Olen. This last some represent as a Lycian, others as an Hyperborean, and by many he was esteemed an Egyptian. He was also reputed by some to be the inventor of verse, and the most ancient priest of Phœbus. These hymns grew, by length of time, obsolete, and scarcely intelligible. They were, however, translated, or rather imitated, by Pamphos, Rhianus, Phemius, Homer, Bion, Proconnesius, Onomacritus, and others.—Many of the sacred terms could not be understood nor interpreted; they were, however, retained with great reverence; and many, which they did attempt to decypher, were misconstrued and misapplied. Upon this basis was the theology of Greece founded; from hence were the names of Gods taken; and various departments attributed to the several deities. Every poet had something different in his theogony; and every variety, however inconsistent, was admitted by the Greeks without the least hesitation. From these ancient hymns, and misconstrued terms, Pherecydes of Syrus planned his history of the gods, a work which, there is reason to think, was the source of much error.

Such were the principles which gave birth to the mythology of the Greeks; from whence their ancient history was, in a great measure, derived. As their traditions were obsolete, and filled with extraneous matter, it rendered it impossible for them to arrange properly the principal events of their country. They did not separate and distinguish; but often took to themselves the merit of transactions which were of a prior date, and of another clime. These they adopted and made their own. Hence, when they came to digest their history, it was all confused; and they were embarrassed with numberless contradictions and absurdities, which it was impossible to remedy. We have already alluded to another reason for the obscurity in the Grecian history, even after letters had been introduced among them. They had a childish antipathy to every foreign language; and were equally prejudiced in favour of their own. This was attended with the most fatal consequences. They were misled by the too great delicacy of their ear; and could not bear any term which appeared to them to be barbarous and uncouth. On this account, they either rejected foreign appellations, or so modelled and changed them, that they became in sound and meaning essentially different. And as they were attached to their own country and its customs, they presumed that every thing was to be looked for among themselves. They did not consider, that the titles of their gods, the names of cities, and their terms of worship, were imported; that their ancient hymns were grown obsolete; and that time had wrought a great change. They explained every thing by the language in use, without the least retrospect or allowance; and all names and titles from other countries were liable to the same rule. If the name was dissonant and disagreeable to their ear, it was rejected as barbarous; but if it was at all similar in sound to any word in their language, they changed it to that word; though the word were of Syriac original, or introduced from Egypt or Babylonia.

If the preceding observations be correct, it would follow, that we must look to other nations, and ascend to a more remote antiquity than the fabulous annals of Greece, for the origin of that superstition, which, under many modifications, appears to have prevailed almost universally throughout the world. Accordingly, Mr. Bryant, of whose theory we are now giving a concise exposition, has expended a great deal of labour, ingenuity, and learning, in an attempt to prove that the ancient mythology was founded upon an union of the worship of the heavenly host with the commemorative rites of the deluge.

We may reasonably suppose, says this learned writer, that the particulars of this extraordinary event (the deluge) would be gratefully commemorated by the patriarch himself, and transmitted to every branch of his family; that they were made the subject of domestic converse, where the history was often renewed, and ever attended with a reverential awe and horror; especially in those who had been witnesses to the calamity, and had experienced the hand of Providence in their favour. In process of time, when there was a falling off from the truth, we might further expect that a person of so high a character as Noah, so particularly distinguished by the Deity, could not fail of being reverenced by his posterity; and when idolatry prevailed, that he would be one of the first among the sons of men to whom divine honours would be paid. Lastly, we might conclude, that these memorials would be interwoven in the mythology of the gentile world; and that there would be continual allusions to those ancient occurrences in the rites and mysteries, as they were practised by the nations of the earth. Accordingly, Mr. Bryant endeavours to prove, that the history of the deluge was religiously preserved in the first ages; that every circumstance attending it is to be met with among the historians and mythologists of different countries; and that traces of it are to be particularly found in the sacred rites of Egypt and of Greece.

It would lead us into far too wide a field, were we to follow this learned and ingenious author throughout the whole of the illustrations he has given of his theory. We must, therefore, refer our readers to the work itself. In the mean time, we shall only observe, that he attempts to trace the origin of the Pagan mythology to the worship of Ham, or Amon, the son of Noah; and resolves the different titles of the Deity into various attributes of the diluvian patriarch. The theory is illustrated by some curious observations on the worship of the sun, the moon, the ark, the serpent, &c.

We have already observed, that the Greeks most prebably derived their mythology from Egypt and the East; the Romans, on the other hand, derived theirs, in a great measure, from the Greeks. It is natural to suppose that many changes must have taken place in the course of those transmissions, and that much confusion should have been created by the multiplicity of names and of attributes. Cicero, in his treatise, *De Natura Deorum*, has a curious passage upon this subject. *Quanquam*, says he, *quem potissimum Herculem colamus, scire velim: plures enim nobis tradunt ii qui interiores scrutantur et reconditas literas. Antiquissimum Jove natum, sed item Jove antiquissimo: nam Joves quoque plures in priscis Græcorum literis invenimus. Ex eo igitur et Lysito est is Hercules, quem concertasse cum Apolline de tripode accepimus. Alter traditur Nilo natus, Ægyptius; quem aiunt Phrygias literas conscripsisse. Tertius est ex Idæis Dactylis, cui inferias afferunt. Quartus Jovis est, et Asteriæ Latonæ sororis, quem Tyrii maxime colunt; cujus Carthaginem filium ferunt. Quintus in India, qui Belus dicitur. Sextus hic ex Alcumena quem Jupiter genuit; sed tertius Jupiter: quoniam, ut docebo, plures Joves accepimus.* So far Cicero; but Varro mentions no less than forty of this name, who were all reputed Deities. On the other hand, we find that the same Deity was worshipped by various nations under different names. To give one example, Macrobius informs us that the sun was worshipped under the names of Adonis, Attis, Osiris, Horus, and Liber; and Ausonius says, that Bacchus, Osiris, Phanax, Dionusus, Liber, and Adoneus, were one and the same deity.

> "*Ogygia me Bacchum vocat;*
> *Osirin Ægyptus putat;*
> *Mysi Phanacem nominant;*
> *Dionuson Indi existimant;*
> *Romana sacra Liberum;*
> *Arabia gens Adoneum.*"

It would appear, in short, that the whole mythology of the ancients was originally derived from one common superstition, diversified, no doubt, by the genius and fancy of different nations, in some more gross, in others more refined, but proceeding from a gradual corruption of the true religion, and an intermixture of the fabulous with the true.

The earliest annals of the most ancient nations generally contained a rude system of cosmogony and theogony. Of these, however, if we except the writings of the sacred historian, Moses, but few, and these very imperfect fragments, have been preserved. The Chaldeans were undoubtedly one of the most ancient nations in the world. Their history, we are told, had been written by four authors—Berosus, Abydenus, Apollodorus, and Alexander Polyhistor. Of their works, however, we have only some fragments preserved in Josephus, Eusebius, and Syncellus. In the last, we find a small piece of Berosus upon their theogony; in which we are told that a monster, half man and half fish, rose from the Red Sea, and made his appearance near a place in the neighbourhood of Babylon. This man, or monster, abode with men by day, without food, and taught them the knowledge of letters and sciences, and whatever could contribute to civilize their manners. At sun-set, he withdrew into the sea, and spent the night in the waters. This monster, Oannes, is said to have written a book about the origin of things, in which he taught that there was a time when all was water and darkness, and that all animals were of a monstrous and irregular make, like the representations to be seen of them in the temples of Belus. It was added, that a woman, named Omcroca, (probably the sea.) was mistress of the universe, and that Belus clove her asunder, formed earth of the one part, and heaven of the other, and put all those monsters to death. Then this god divided the darkness, separated earth from heaven, and ranged the universe in order; and seeing the world desolate, he ordered one of the gods to cut off his head, to mix with earth the blood that flowed from the wound, and of it to form men and animals; after which he framed the stars and planets, and thus finished the production of all beings. This gross system of cosmogony may be traced, we think, to some corrupted tradition respecting the Noachic deluge, and the Mosaic account of the creation. In other traditions of the Chaldeans, we have an enumeration of the first ten generations, and an account of the deluge, which, in many particulars, coincides wonderfully with that given by Moses.

The Phenicians also had their cosmological traditions; and their mythological system, which was nearly the same with that of the Egyptians, seems to have been the source from whence the theogony of the Greeks was derived. Sanchoniathon, priest of Berytha, had written upon the cosmogony and theogony of the Phenicians, but his work perished in the wreck of time. It was extant, however, in the first ages of Christianity; for about the reign of the Antonines, Philo of Byblos translated it into Greek. In his preface, Philo remarks, that Sanchoniathon had made an exact scrutiny into the writings of Thaautus, the Phenician Mercury, the same with the Thoth of the Egyptians.* This translation, which appears to have been interpolated by Philo, and adapted to the ideas of the Greeks in his time, has also perished: All that we have of it is a long fragment preserved by Eusebius. But Eusebius also appears to have mixed up his own reflections with those of the Greek translator; so that this fragment cannot now be regarded as an authentic document.

In the theogony of this author, however, we may trace the original of that system of mythology which appears to have been afterwards transplanted into Greece. We find there the traditions relative to the Dioscuri or Cabiri, Uranus and Ge, Chronos or Saturn, Jupiter, Apollo, Minerva, Hermes, &c. The theogony and cosmogony of the Egyptians were pretty nearly the same with those of the Phenicians; and both were evidently derived from the same source. Besides the original divinities of that ancient people, Osiris and Isis, (the Sun and Moon.) we again find, among their great gods, Saturn, Rhea, Jupiter, Juno, Vulcan, Vesta, Mercury, &c. We have already observed that the Greeks derived their mythology from Egypt and Phenicia. They, however, appear to have corrupted the traditions which they have received, to have adapted them to their own manners and ideas, and applied them to their own history. It would be superfluous in us to give any farther account of a system of mythology which is familiar to us from our early years.

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* If we are not mistaken, the appellation Thaautus, Thut, Thoth, has been transmitted through the ancient languages down to modern times; and may be traced in the Θεος of the Greek, the *Deus* of the Romans, the German *Theut* or *Teut*, the French *Dieu*, and the English *Deity*.

The Chinese lay claim to great antiquity as a nation. Their fabulous records are said to reach to many myriads of years before the Mosaic era of the creation. The missionaries, who are the only sources of our information respecting the earliest periods of the history of this people, represent them as having retained the religion of Noah many centuries after the foundation of their empire by Fo-hi; and in their ancient books, no vestiges of an idolatrous worship are to be found. The emperor Fo-hi, whose birth is said to have been miraculous, is represented as possessed of immense intellectual powers. He taught his countrymen the whole art of agriculture; invented boats and nets for fishing, the art of fabricating porcelain, the management of silk worms, the manufacturing of silk, &c. In short, the invention of all the useful arts is ascribed to Fo-hi. But their religion seems to have gradually degenerated into a species of atheism.

The sect of the Faose appeared in China near six hundred years before Christ. It was founded by the philosopher, Lao-Kiun, of whose birth the most extraordinary and absurd stories are told. His morals seem to have approached near to those of Epicurus; but his physical doctrines are wrapt up in impenetrable obscurity. Those who made profession of this sect were much addicted to magic and alchemy, in order, it is said, to discover the secret, by means of which they might become immortal. The author of this sect was himself ranked among the gods; a stately temple was erected to him; and the emperor Huim Tsong caused the statue of this new God to be brought into his palace.

About 551 years before the Christian era appeared the famous Chinese philosopher, Con-fut-se, or Confucius. His birth also is represented in the legendary tales of the Chinese as miraculous. He lived an austere, ascetic life, taught and inculcated the doctrines of pure morality, and, at his death, left behind him a great reputation for superior wisdom.

About the 65th year of the Christian era, a new sect was introduced into China. The emperor, Ming-ti, struck with some words which Confucius had often repeated, viz. *that it was in the west they should find the Holy One*, sent ambassadors into India in quest of him, and to learn the law he taught. Those envoys believed they had at last found him out among the worshippers of an idol, named Fo, or Foe. They accordingly transported into China several images of this idol, together with the fables and superstitions of which the Indian books were full, the doctrine of the Metempsychosis, or transmigration of souls, &c. The worship of Foe, once introduced, made a most rapid progress all over China, Japan, Siam, &c. The priests of Foe are called among the Siamese, *Talapoins;* by the Tartars, *Lamas;* by the Chinese, *Ho-chang;* and by the Japanese, *Bonzes;* by which last appellation they are most commonly known in Europe. A vast number of temples were erected to this idol in China; and an inexhaustible store of the most monstrous fables concerning the life and adventures of Foe were propagated by his disciples, the Bonzes—the most ignorant, the most superstitious, and the most despicable of all mortals.

The Hindoos, like the other eastern nations, appear to have retained, for a long period, the worship of the true God. In the course of time, however, idolatry broke in among them, and overspread the country; and the genuine history of the origin of the world was corrupted and disguised under a variety of fictions and allegories. All mankind, we are told, are sprung from their supreme God, Brahma, or Brimha, who is said to have produced as many worlds as there are parts in his body. The first of these worlds, which is above the heavens, sprung from his brain; the second, from his eyes; the third, from his mouth, &c. According to another tradition, Brahma produced the Brahmins from his mouth, to pray, to read, to instruct; the Chiltern from his arms, to draw the bow, to fight, to govern; the Bice, from his belly or thighs, to nourish, to provide the necessaries of life by agriculture and commerce; the Soder, from his feet, for subjection, to serve, to labour, to travel. The Hindoos have also some mythological traditions, which obviously appear to relate to the general deluge; but the history is adapted to their own religious tenets. But the vulgar religion of the ancient Hindoos appears to have been that of Foe, which, as we have already observed, was imported from India into China, and which probably came originally into India from Egypt. The traditions respecting this personage are so ridiculous and extravagant, that our readers may spare us the trouble of reciting them. One of the principal doctrines inculcated by Foe and his disciples was the metempsychosis, or transmigration of souls. Some have imagined that this doctrine gave rise to the multitude of idols reverenced in every country where the religion of Foe prevailed, and particularly to the worship of animals. To this doctrine, too, may be ascribed the story of the incarnations of Vishnou—who, along with Bud, Butzen, or Budda, is held to be the same with Foe. An infinitude of fables concerning him were propagated by his disciples, after his death. They pretended that their master was still alive; that he had been already born 8000 times, and that he had successively appeared under the figure of an ape, a lion, a dragon, an elephant, a boar, &c. At length he was confounded with the supreme God; and all the titles, attributes, operations, perfections, and ensigns of the Most High were ascribed to him. There are other wild and extravagant mythological and cosmological notions of the Indians, for an account of which we must refer our readers to the authors who have written upon the subject.

The mythology of the Persians is fully as extravagant as that of the Hindoos. Anciently, as we learn from Herodotus, Strabo, and other writers, they worshipped the Sun, under the name of Mithras, and also paid adoration to Fire, as representing the Sun. This is the religion of the Magi, which is said to have been introduced by Zoroaster. They also acknowledge the good and bad principle, under the names of Oromazes and Arimanius; and they hold that, before the creation of Adam, this globe was inhabited by a race of beings called *Peri* and *Dives*; the former, described as beautiful and benevolent; the latter, as deformed, malignant, and mischievous. These beings make a great figure in the Persian poetry and romances. Indeed, Persia appears to be the genuine classic ground of eastern mythology, and the source of chivalry and romance; which seem to have been propagated from thence to the regions of Scandinavia, and to the remotest corners of Europe.

For an account of the mythology of the Americans we must consult the annals of Peru and Mexico. The most remarkable article in the Peruvian religion is the worship of the Sun, and the pretended extraction of their first Inca, Manco-Capec, and his consort Ocolla, from that luminary. The idolatry of Peru was mild and beneficent; that of Mexico, gloomy and sanguinary.

There are but few vestiges remaining of the superstitions of the Celtic nations, and the Druidical worship. The mythology of the northern nations of Europe, on the other hand, is uncommonly curious and entertaining. Their mythological traditions, which rival the extravagance of the Peruvian fables, are to be found in the Edda and Voluspa. The Edda appears to have been compiled in Iceland in the thirteenth century, but, by whom, is uncertain. The greater part of this work is filled with the exploits and adventures of their supreme divinity, Odin, or Wodan. The greatest earthly happiness, according to the notions of those people, consisted in warlike enterprises; and, accordingly, Odin is represented as the God of Battles, and of irresistible prowess. He is supposed to have emigrated from the east; but from what country, or at what period, is uncertain. His palace is called *Valhal* or *Valhalla*, and is situated in the city of Midgard, where the souls of heroes who have bravely fallen in battle enjoy supreme felicity. There they are represented as spending the day in mimic hunting matches, or imaginary combats. At night they assemble in the palace of Valhalla, where they feast on the most delicious viands, dressed and served up by the *Valkyriæ*—virgins adorned with celestial charms, and blooming with perpetual youth. One of their highest pleasures is drinking mead (the nectar of the Scandinavian heroes) out of the skulls of enemies whom they had killed in their earthly battles. Slupsur, the horse of Odin, is equally celebrated with his master. The hell of the Scandinavians was called *Hela*; and *Lok* was the evil genius or devil of the northern nations, resembling very nearly the Typhon of the Egyptians. *Signa or Sinna* was the consort of Lok; from whence is derived the English word *sin*. They had also a number of dwarfs and giants, who performed a variety of exploits, and were exhibited in the most frightful attitudes. Properly speaking, however, *Thor* was the principal divinity of the Icelanders and Norwegians; and Odin, or Wodan, of the Swedes, Danes, and North Germans. According to Snorri's description, *Thor* was represented as a person of colossal stature, with a hammer in his hand. The name *Asi* was a term of later introduction, which was employed as a general designation of the northern divinities; and their residence was called *Asgaard*, or the city of the *Asi*. They had also other deities, such as *Freya*, *Niord*, the *Nornes*, or destinies, &c. and they believed in the agency of elves, fairies, and other spirits.

The word *Voluspa* is compounded of *Vola*, mad or foolish, and *Spa*, a prophecy. The latter part of this compound may be recognised in the Scotch word *spae*. This work consists of between 200 and 300 lines, and contains an account of the cosmological notions of the northern nations. The prophetess begins with a description of the chaos; and then proceeds to the formation of the world, and the creation of the different species of its inhabitants. She then explains the employments of the Nornes, or destinies, the functions of the deities, their most memorable adventures, their disputes with Lok, &c. and she concludes with a long and animated description of the final state of the universe, and its dissolution by a general conflagration. The mythology of the north of Europe bears, in some of its features, so close a resemblance to the fictions of the eastern nations, as to afford some ground for the belief, that they originally flowed from one common source.

In this article, our limits have permitted us to give only an outline of this interesting subject. Those who are desirous of obtaining more ample information, respecting the mythology and cosmogony of various ages and nations, are referred to the following works:

Bannier's *Mythology and Fables of the Ancients explained from history.* Bryant's *Ancient Mythology.* M. G. Herrmann, *Mythologie der Griechen.* Hyde's *Relig. vet. Pers. &c.* D'Herbelot's *Bibl. Orient.* Anquetil's *Zend Avesta.* Halhed's Introduction to his translation of the *Code of Gentoo Laws. Asiatic Researches*, passim. The treatise *De Dea Syria*, generally ascribed to Lucian. Selden *de Diis Syr.* Kircher's *Oedip. Voss. de Orig. et Prog. Idol.* Jablonski's *Panth. Egypt.* M. Gebelin's *Monde Prim. Edda Saemundar hinns Froda, &c.* Copenhagen, 1786. Goranson's *Hyperboreorum Atlantiorum, seu Suigotorum et Nordmanorum Edda, &c.* Mallet's *Northern Antiquities.* F. Rühs, *Die Edda, &c.* Berlin, 1812. (z.)

N.

NACOGDOCHES, a town of the province of Texas, about 120 miles west of Natchitoches, in Louisiana, North Lat. 31° 26′, and 94° 20′ West from Greenwich. It is situated in a fine healthy and well watered country, but is nevertheless an inconsiderable place, with only a few houses, a Roman Catholic church, and a small, but indefensible, fort.

DARBY.

NAIRN, a royal borough, and county town of Nairnshire, is beautifully and commodiously situated on the west bank of the river Nairn, which enters the Moray Frith eleven miles from Forres. The houses in the High-street, that lies east and west, are neat and elegant, from which many narrow lanes, extending to the river on one side, and to a cultivated plain of more than 400 acres on the other, exhibit buildings of a very inferior construction. The gaol and town-hall are situated in the middle of the street; and the church and cemetry occupy a green head-land, projecting into the course of the river on the southern side of the town.

The first charter now extant was granted by James VI. in the year 1589, being the renewal of a charter by Alexander I.; and the revenue of the borough is derived from a considerably extensive moor, let on various leases—from feu-duties and the tolls of six stated fairs in the year, and the weekly market. The government of the borough is committed to a provost, 3 baillies, a dean of guild, treasurer, and 11 councillors. The whole trades form one incorporation.

The police is well conducted, and the streets are kept clean and well lighted. A considerable wing of Nairn, stretching towards the shore, is occupied by fishermen, who use the Celtic language, which is not understood by the other citizens; and in consequence of this, one-half of the service of the public worship in the church is delivered in that tongue. This circumstance suggested a joke, attributed to James VI. who, being displeased by the compliments of a courtier on the population of the cities of England, is said to have replied, "that none of them equalled the extent of one of the cities of his native kingdom, which was so large, that one-half of the the inhabitants did not understand the language of the other."

The school is well conducted, and the different branches of education are taught with success. The number of scholars is seldom below 80, and often above 100. A school for girls is also supported at the public expense. The castle hill is situated on the south side of the town, on the banks of the river, where a royal fort once stood. The castle was placed, at a very remote period, nearer the shore, on the influx of the river, which flowed half a mile farther westward than at present, and vestiges of it are supposed yet to remain a considerable way within the bed of the ocean.

Mr. Telford has been employed in surveying the ground for constructing a commodious harbour, and it is calculated this great improvement may be made for the sum of 3000*l.*: the accommodation to the inhabitants of Nairn would thus be much increased, if the intercourse on the Moray Frith, which must result from the Caledonian canal, were more frequent. Nine boats are employed in the white and salmon fishery, and 20 or 30 in that of herring. The establishment of a wool-carding manufactory has been very useful, and the plaiting of straw for England has been lately introduced. In 1794 the town contained 1100 inhabitants, and at present they amount to 2000.

NAIRNSHIRE, a small county in the north of Scotland, is bounded on the north by the Moray Frith; on the east and south by Morayshire; and on the west by Inverness-shire. It is situated between 57° 22′ and 57° 40′ North Lat. and 3° 35′ and 3° 47′ West Longitude. It extends from 16 to 18 miles in length, and its greatest breadth is ten miles. The whole of this county, excepting Ferintosh, which is encompassed by Ross-shire, and wholly unconnected with any other part of the county, was formerly included in the province of Moray It consists of four entire parishes, Ardclauch, Auldearn, Calder, and Nairn, as also a part of the parish of Dyke in Morayshire, of Urquhart in Ross-shire, of Croy, Moy, and Petty in Inverness-shire. The county contains nearly 128,000 acres.

This county presents a varied intermixture of low land, hilly, and mountainous district. The flat plain of the lower part of the parish of Calder rises towards the south into a hilly tract, and elevates its boundary with Moy into a mountainous country. In the parish of Nairn, whose form resembles the letter X, the ground on the north of the river is flat and level, and on the south a gradual acclivity is terminated in one corner of the parish by the hill of Urchany. The part of the parish of Croy lying to the north and north-west of the Nairn is almost one continued ridge; but the banks of the Nairn are well cultivated or planted. The parish of Ardclaugh is a hilly district, corresponding with the Gaelic word, which signifies high stony ground, and on this account it furnishes little pasture that is not mixed with heath.

The climate is in general serene, dry, and salubrious, but more inclement and rainy in the higher parts of the county. It is worthy of remark, that in the parish of Ardclauch, though the air is supposed to be healthy, and many of its inhabitants surpass the 70th and 80th year of their age, yet the inhabitants, both young and old, are peculiarly subject to the erysipelas.

The greatest part of the soil in this county is poor, thin, stony, and generally of a sandy quality. In the eastern quarter of Auldearn, the soil is a strong clay, of a red colour, and produces abundant crops, but is difficult to cultivate. The southern part of the county of Nairn is of a rich heavy mould, and the banks of the river consist of sand mixed with clay. The greatest part of the parish of Croy presents a white moorish soil, while along the river a fertile loam abounds of good quality. The soil in the higher part of Calder is a peat morass, covered with brown heath: in some of the lower parts there are plots of moorish rocky ground, but a considerable quantity is a kindly, sharp, and fertile soil. The small number of enclosures, and the great abundance of heath, prove the general badness of the soil, and poverty of its cultivators. If, however, the same spirit should arise in this bleak county which has so long distinguished Norfolk, once the most barren spot in England, and a judicious use of marl, lime, &c. be adopted, we entertain no doubt that a great change will soon be effected.

This county is watered by the rivers Findhorn and Nairn, whose banks are covered in many parts with woods and plantations; several elegant seats and romantic old castles diversify the scenery. The castle of Kilravock, on the banks of the Nairn, and that of Cawdor on the delightful burn of the same name, are worthy of notice. Boath, Geddes, and Lethin house merit attention.

Sandstone is very abundant. A very valuable bed of pure marl is contained in the moss and lake of Litie, on the property of Lord Cawdor, extending over a space of 40 acres, and being from 16 to 20 feet deep. It is also supposed, that in the grounds between Boath and the shore, coal might be found, since there is a quarry of dark blue stone, which, like coal, flames in the fire, and does not fall into powder like limestone, on the application of water. Considerable tracts of peat abound also in this county; and fir trees 60 feet long and 3 feet in diameter, have also been discovered in the peat, and used in the roofing of houses.

The agriculture of this county is in a very low state, since there are few inclosures except in the immediate vicinity of large towns, and of gentlemen's seats. David Davidson, Esq. of Cantray, has been justly distinguished for his exertions in ornamenting and improving his property, by bringing 400 acres of waste into a very high state of cultivation, and planting more than 2000 acres. The example of gentlemen farmers are rarely followed very hastily by the adjoining tenantry, whose cautious and calculating habits generally yield only to the successful results of practical farmers. The smallness of the farms militates very much against the introduction of any very lasting change, since few tenants occupy farms amounting to 50*l.* per annum; and the great majority of farms does not exceed 20*l.* The rental of the different farms varies from 2*s.* 6*d.* to 35*s.* per acre.

The whole amount of land under timber of native growth is 4000 acres, and under plantations 6000.

The amount of the inhabitants in 1801 was 8257, and in 1811, 8251. It has only one royal borough, Nairn, and two villages, Auldearn and Calder, and sends a member to parliament alternately with Cromarty.

Temples of the Druids are numerous, and prove this county to have been inhabited from very remote antiquity. It is generally supposed that an artificial green mount, in the parish of Auldearn, had been formed for a court of civil justice when the druidical temples were forsaken. The celebrated historian George Buchanan supposes the castle near Nairn was taken by the Danes in the reign of Malcolm I.

The village of Auldearn is distinguished as the spot where the Marquis of Montrose, in 1645, obtained a most decisive victory over the friends of the presbyterian form of church government, in which he lost only 20 men, while 2000 of the enemy were slain, many prisoners captured, and the whole baggage, much wealth and ammunition, with 16 standards, taken. In the parish of Croy, not far from the ridge of moorish grounds, on the side towards the river Nairn, the ever memorable action of Culloden was achieved. The royal army consisted of 8811, and the rebel of 8350. The victory obtained on this day put a final period to the hopes of the Pretender, whose history, and that of his family, must ever remain a valuable lesson to all future generations. Only 50 of the royal army fell, of whom 6 were officers, while the number of the rebels killed in the action and pursuit has been computed at 2500.

See MORAYSHIRE. *Statistical Account of Scotland*, by Sir John Sinclair, Bart. *A Survey of the Province of Moray.* The Rev. Mr. Leslie's *General View of the Agriculture of the Counties of Nairn and Moray.*

NAMUR, a city of the Netherlands, and capital of a province of the same name, is situated in a valley at the junction of the Sambre and the Meuse, the greater part of the town being placed between two hills on the right of the Sambre. The town is well built, and its streets wide and clean, and the houses are built of stone of a blue colour, with red and black veins. The principal public edifices are the cathedral and the church of the Jesuits. The town is defended by a citadel, erected on the summit of a precipitous rock. In the neighbourhood of Namur there are numerous mines of copper and iron, and considerable manufactures of fire-arms, swords, knives, scissors, and other hardware articles. Ropes, leather, thread, and tobacco, are also manufactured in considerable quantities. Namur had formerly a population of 30 000, but it has diminished to 15,085. East Long. 4° 51′ 7″, and North Lat. 50° 28′ 30″.

NANCY, one of the finest towns in France, and the capital of the department of the Meurthe, is beautifully situated in a plain on the left bank of the Meurthe. The town, which is large and well built, consists of the old and new town, and two well-built suburbs. The new town, which was begun in the 16th century, is large and handsome, and contains spacious streets, with many elegant houses. The gates are particularly splendid. The eastern and western ones, which are similar, terminate two fine streets, which unite in the square built by Stanislaus. This square, encircled by an iron railing, contains very splendid houses, and has a beautiful fountain at each of its four corners The old town is a confused mass of houses without taste, and the streets are narrow and crooked. It has two handsome squares, one of which is planted with trees. The principal public buildings are, the ancient palace, the town-hall, the cathedral, the church of the Cordeliers, containing the tombs of the ancient Dukes of Lorraine, and also that of Charles the Bold, Duke of Burgundy; the ci-devant cloister of the Franciscans, at the end of the Fauxbourg of St. Pierre, containing the mausoleum of king Stanislaus, which is the chef-d'œuvre of Giraidin. The expense of the buildings with which Stanislaus adorned this town was about 3 585.346 livres. There are also in Nancy several hospitals and houses of charity, and some literary establishments. The academy was founded in 1751, and has a considerable library. The principal manufactures are those of linen and woollen goods, and its chief trade is in corn and wine. See the *Compte General de la dépense des édifices et batimens que le Roi Stanislaus a fait construire pour l'embellissement de la ville de Nancy depuis* 1751 *jusqu'en* 1759 Population 29.740. East Long. 6° 10′ 31″. North Lat. 48° 41′ 55″.

NANGASACKI, a large sea-port town of Japan, situated at the south-west extremity of the island of Ximo. The place comprehends the Dutch town and the Japanese town. The former consists of several large fire-proof stone houses, and of various houses built of wood, clay and tiles. The Japanese town is divided into the inner, which contains 26 streets, and the outer, which contains 61 streets. The principal public buildings are 62 temples built on eminences, the palaces of the two governors, and those of other princes and grandees; and the prison, or Goknia, composed of a hundred separate huts or cages. The brothel consists of two handsome streets, shut at each end by strong gates, where the prostitutes are kept, and let out to hire. An account of the harbour of Nangasacki, and other particulars respecting its recent history, will be found in our article JAPAN See also Krusenstern's *Voyage round the World*. chap. xii. and xiii Long 230° 8′ west of Greenwich, and North Lat. 32° 45′ 40″.

NANKIN. See CHINA.

NANTASKET This name is applied to one of the main entrances into the harbour of Boston, south of the Lighthouse. Nantasket road affords good anchorage with from 5 to 7 fathoms water.

DARBY.

NANTES, a city of France, and capital of the department of the Lower Loire, is situated on the right bank of the Loire, which here divides itself by means of islands into six separate branches, which are crossed by a series of bridges, extending about a league in a straight line. The town of Nantes is finely situated on the declivity and summit of a hill. The city, exclusive of the suburbs, is of an oblong form, extending along the banks of the river. In general, the houses are old and irregularly built, and the walls of many are leaning considerably from the perpendicular. The suburb of La Fosse contains the most elegant houses, and is superior to any part of the town in beauty.

The principal public buildings of Nantes, are the Gothic cathedral, adorned with the tombs of the Dukes of Brittany; the castle, which is a large building commanding the harbour, the town-hall, the house of the prefect, the theatre, and a handsome column 70 feet high; there is also a lyceum, a public library, a botanical garden, a museum of natural history, agricultural and commercial societies, and schools of anatomy and surgery.

The chief manufactures carried on at Nantes, are those of rope-making, spinning, weaving of woollen and linen goods, cotton printing, earthenware; glass, and articles of hardware are also manufactured; and ship-building is carried on to a considerable extent.

Nantes carries on a considerable foreign trade with the west and north of Europe, and with America, the West Indies, and the coast of Guinea. When St. Domingo formed part of France, no fewer than 150 vessels belonging to Nantes were employed in the trade with the West Indies. The coasting and inland trade of Nantes is very extensive, and is highly favoured by the Loire and its tributary streams. From the shallowness of the river, however, vessels exceeding 80 or 90 tons are obliged to unload at Paimbœuf, about 20 miles below Nantes, and the merchandise is carried to that city by means of lighters. Population 73,879. West Long. 1° 22′ 44″, and North Lat. 47° 13′ 6″.

NANTUCKET, an island and county of Massachusetts, lying in the Atlantic ocean, ten miles a little south of east from Martha's Vineyard, and fourteen south of Cape Malabar, in Barnstable county. Nantucket is nearly in form of a crescent, about 16 miles in length, with an area of 50 square miles; situated between North Lat. 41° 13′, and 41° 22′; and between 69° 56′, and 70° 13′ West from Greenwich. Similar to all other islands, the climate of Nantucket is mild when compared to that of the adjacent continent. The soil, though light and sandy, is tolerably productive. Meadow grasses grow abundantly. The right of landed property is held in common by the inhabitants. The inhabitants are in general engaged in a seafaring life, and have always been remarkable for their activity and hardy robust temperament, and their admirable knowledge and enterprise as seamen. In both wars between the United States and Great Britain, the inhabitants of Nantucket evinced their patriotism, and were from their exposed situation severe sufferers from the cruisers of the common enemy. Their industry and experience have amply restored their prosperity; they have now near fifty sail of vessels, averaging three hundred tons burthen, engaged in the whale fishery. The manufacture of Spermaceti employs on the island a capital of upwards of 600,000 dollars. A long and dangerous shoal extends east and north-east from Nantucket, the exact extent and position of which has never been very exactly delineated.

The chief town on the island is called by the same name, Nantucket, standing on the north side of the island, at North Lat. 41° 15′ 30″, and 70° 05′ West Long. from Greenwich, and 6° 55′ East from Washington city; about 45 miles south-east from New Bedford, and 90 south-east by south from Boston.

The form of Nantucket island renders the whole northern part a bay, the concave part of the crescent extending to the south. The town of Nantucket stands at the bottom of this bay, upon an excellent and well sheltered harbour, into which large vessels cannot enter, upon account of a bar of sand at its entrance.

There is in the town of Nantucket two Banks and two Insurance Companies. The inhabitants of the whole island in 1810 amounted to 6807, and in 1820, to 7266.

DARBY.

NANTWICH, a town of England, in Cheshire, is situated in a beautiful vale on the banks of the river Weaver, which divides it into two unequal parts.

It consists of about 800 houses, arranged in two principal and several smaller streets. The church, built in the form of a cross, has an octagonal tower and some finely ornamented windows. The mansion house is a neat modern building. There is in the town a free school, a charity school, several alms-houses, and a good workhouse erected in 1780. The principal manufactures of Nantwich are those of salt and shoes, of which great quantities are sent to London. The cotton manufacture was also extended to this town, and gloves made to a considerable extent. The Chester canal terminates in a broad basin near the town. Population 3463.

NAPIER, or Neper, John, Baron of Merchistoun, the celebrated inventor of the Logarithms, was the eldest son of Sir Archibald Napier of Merchistoun, Master of the Mint in Scotland, and was born at Merchistoun in the year 1550. Having given early indications of industry and talents, his education was conducted with great care, and, after going through the ordinary course of study at the college of St. Andrew's, he made the tour of the Low Countries, France, and Italy, where he is said to have applied himself to the mathematics. On his return from the continent, he devoted himself in a particular manner to the study of geometry and the Scriptures; and, in the year 1593, he published his essay on the Apocalypse, under the title of *A Plain Discovery of the Revelation of St. John.* This work gained our author great reputation, and was translated into several foreign languages.

In the year 1596, Napier wrote a letter, addressed to Anthony Bacon, (the original of which is in the Archbishop of Canterbury's library at Lambeth,) entitled, "Secret inventions necessary in these days for the defence of this island, and withstanding strangers, enemies to God's truth and religion." *

The attention of Baron Napier was about this time engrossed by his discovery of logarithms. Having occasion, from his attachment to astronomy, to make many numerical calculations in spherical trigonometry, he set himself to find out some method of diminishing the labour of calculation. Wood informs us, in the *Athenæ Oxonienses*, on the authority of Oughtred and Wingate, "that one Dr. Craig, a Scotchman, coming out of Denmark into his own country, called upon John Napier, Baron of Marcheston, near Edinburgh, and told him, among other discourses, of a new invention in Denmark, (by Longomontanus, as 'tis said,) to save the tedious multiplication and division in astronomical calculations. Napier being solicitous to know farther of him concerning this matter, he could give no other account of it than that it was by proportionable numbers. Which hint Napier taking, he desired him at his return to call upon him again. Craig, after some weeks had passed, did so, and Napier then showed him a rude draught of what he called *Canon Mirabilis Logarithmorum*; which draught, with some alterations, he printed in 1614. It came forth into the hands of our author Briggs, and into those of William Oughtred, from whom the relation of this matter came."

Although there seems to be no reason for doubting these facts, yet, excepting the remark that Napier took the hint from his conversation with Dr. Craig, they are in no respect inconsistent with the statement made in the preface to Napier's work, where it appears that he was led to the investigation from the difficulties which he had experienced in his trigonometrical calculations.

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* Some account of this letter has already been given under our article Burning Instruments.

The work, which contained this great invention of artificial numbers for abridging calculation, appeared in 1614, under the title of *Logarithmorum Canonis Descriptio*, of which we have already given a particular account, together with Dr. Briggs's improvements, in our article on LOGARITHMS.

In consequence of the correspondence which took place between these eminent men, the Baron seems to have invited Briggs to visit him in Scotland. "Napier, Lord of Merchistoun," says Briggs, in a letter to Archbishop Usher, dated March 10, 1615, "hath set every head and hand at work with his new and admirable logarithms. I hope to see him this summer, if it please God; for I never saw a book which pleased me better, and made me more wonder."

Briggs accordingly made him a month's visit, of which the following curious account is given in the life of Lilly the astrologer.

"I will acquaint you (says Lilly) with one memorable story, related unto me by John Marr, an excellent mathematician and geometrician, whom I conceive you remember. He was servant to king James I. and Charles I. When Merchistoun first published his logarithms, Mr. Briggs, then reader of the astronomy lectures at Gresham college in London, was so surprised with admiration of them, that he could have no quietness in himself until he had seen that noble person, whose only invention they were; he acquaints John Marr therewith, who went into Scotland before Mr. Briggs, purposely to be there when these two so learned persons should meet. Mr. Briggs appoints a certain day when to meet at Edinburgh; but failing thereof, Merchistoun was fearful he would not come. It happened, one day, as John Marr and the Lord Napier were speaking of Mr. Briggs; 'Ah, John, (saith Merchistoun) Mr. Briggs will not now come; at the very instant one knocks at the gate; John Marr hasted down, and it proved to be Mr. Briggs, to his great contentment. He brings Mr. Briggs up into my Lord's chamber, where almost one quarter of an hour was spent, each beholding other with admiration before one word was spoken. At last Mr. Briggs began. 'My Lord, I have undertaken this long journey, purposely to see your person, and to know by what engine of wit or ingenuity you came first to think of this most excellent help unto astronomy, viz. the logarithms; but, my lord, being by you found out, I wonder no body else found it out before, when now, being known, it appears so easy.' He was nobly entertained by the Lord Napier, and every summer after that, during the Laird's being alive, this venerable man, Mr. Briggs, went purposely to Scotland to visit him."

Besides his great invention of the logarithms, Baron Napier improved trigonometry with his universal rules or theorems for solving all the cases of right angled spherical triangles, which he calls the *five circular parts*, and of which we shall have occasion to give an account in our article on TRIGONOMETRY. The last production of this eminent mathematician was his *Rabdologia, seu numerationis per Virgulas, Libri Duo*, which appeared in 1617, and which was dedicated to the Chancellor Seton. This work contains the description and use of an apparatus, called Napier's Bones or Rods, and other ingenious methods of abridging calculation. The description of the Bones will be found in our article ARITHMETIC. Napier did not long survive the publication of this work. He died at Merchistoun on the 3d April, O. S. 1617, in the 68th year of his age; and such was the extent of his reputation, that the illustrious Kepler dedicated to him his Ephemerides, which were published in 1617; and it appears from many passages in his letter, that he reckoned Napier the greatest man of his age in the particular department to which he had directed his attention. He was buried in the cathedral church of St. Giles, on the eastern side of its northern entrance, where a stone tablet, bearing a Latin inscription, indicates that this is the burial place of the Napiers.

Baron Napier of Merchistoun was twice married. He had only one son, called Archibald, by his first wife, who was a daughter of Sir James Sterling of Keir. By his second wife, a daughter of Sir James Chisholm of Crombie, he had a numerous family, of five sons and five daughters. His eldest son Archibald, who attained to eminence in his father's life time, was made a privy counsellor by James VI., in whose reign he held the several offices of treasurer-depute, justice-clerk, and senator of the College of Justice; and he was raised by Charles I. in 1627, to the peerage, by the title of Lord Napier. His third son was a pupil of his own in mathematics, and to him he bequeathed the care of publishing his posthumous works.

For farther information respecting the life and writings of that eminent individual, see *The account of the Life, Writings, and Inventions of John Napier of Merchiston*, by the Earl of Buchan. Perth, 1787.

NAPLES, an ancient kingdom in the south of Italy, is bounded on the north-west by the states of the Church, on the west and south by the Mediterranean, on the north-east by the Adriatic. It reaches from 13° 18′ to 18° 50′ of east longitude, and from 37° 46′ to 42° 55′ of north latitude. The length, from the limits of the Pope's territory on the north, to the extremity of Calabria on the south, is about 360 British miles; the greatest breadth 120; the superficial extent being estimated at something more than 30,000 square miles, and the population at 5,000,000 souls. It is divided into 15 provinces, and includes several small islands in both the seas which bound it.

The general aspect of the country is variegated and picturesque. The *spine of Italy*, the Apennine chain of mountains, passing through this tract, and sending off shoots in several directions, gives a character of inequality to the surface; at one time rising into lofty and rugged summits, which merit the epithet sublime; at another swelling into gentle eminences, which, covered with the most luxuriant vegetation, and fringed with a profusion of elegant shrubs, are justly denominated beautiful. Monte Gargano is the principal secondary branch; it starts at right angles from the main ridge, and proceeds eastward to form the promontory whose name it bears. Another secondary branch extends south-eastward into the province of Otranto; the main ridge itself now bending to the south and terminating at the Faro of Messina. The principal summits of this district are the Gran Sasso d'Italia, 8000 feet above the level of the sea; the Velino, 8300; and the Sila, 5000. The famous Vesuvius is an insulated mountain; its volcanic action, not its height, renders it worthy of mention. The elevation of its crater is only 3900 feet.

The climate of Naples exhibits considerable variety. In the mountainous parts of the kingdom, of course, cold is the prevailing characteristic; none of the peaks, however, ascend to the region of perpetual frost. The eastern provinces, on the other hand, being screened by the Apennines, are frequently incommoded with droughts; and some of their vegetable productions, as the aloes and the palm, indicate the approach to a tropical temperature. Calabria is moist and hot. The district around the capital is temperate, and delightful beyond any other in Europe. It is called the Campagna Felix, and well deserves that name. There is a luxurious balminess in the air; an azure brightness in the sky; a magnificence in the atmospheric phenomena, which strike every traveller with admiration. The feeling is heightened by contrast also; you arrive at Naples, from the north, by the Pomptine Marshes; the most insalubrious and dismal country of the world conducts you to the finest. But the beauty and grandeur of the Campagna Felix are not without their drawbacks. The eruptions of Vesuvius are sometimes dangerous, and earthquakes are both frequent and destructive. The year 1783 is still recollected with terror over all the kingdom; and more lately, in 1803, a violent shock was experienced, from which the capital and its neighbourhood sustained great damage.

The soil here is light and sometimes volcanic, but generally fertile; a better system of agriculture might render most of it eminently fertile. A little draining in one place, a little irrigation in another, are often all that the ground asks of the husbandman; but even this he seldom grants. His mode of cultivation is the rudest imaginable. He ploughs the land and sows it annually with corn; and when it will no longer yield him any crop, he leaves it to recover as it likes. Nor will this ignorance and inattention of the farmer appear surprising, if we take his circumstances into view. He is usually a *metayer*, and the terms of the contract are grinding to him. He receives his patch of ground at first stocked by the landlord, and provided with seed and such clumsy implements as he requires, all of which he is bound to replace at the expiration of his lease; he manages the farm by his own labour, and according to his own plan; and *a third* of the produce is his whole reward. In Lombardy *a half* of the produce makes the peasant happy, industrious, skilful: in Naples, *a third* makes him a sloven, a beggar, frequently a smuggler or a robber. The government in Lombardy has secured the terms of the peasant's contract with his master, by law: the government in Naples *treats* with the banditti who infest its dominions, and often pays them a salary to restrain their depredations.

Such a system of husbandry cannot well be productive. It yields wheat, barley, rye, for the internal consumption; besides a remaining quantity of wine and olive-oil for exportation. Nearly a half of the agricultural labour is devoted to the vine; but the management of it is greatly inferior to what may be observed in flourishing wine countries, as in the neighbourhood of Oporto or Bourdeaux. It is not uncommon to find several departments of cultivation carried on by the same person, in the same field. Elms and poplars are often seen planted in rows, and supporting vines, while the intervening spaces are sown with grain or pulse.

The Neapolitan animals are not remarkable for their excellence. Horses no longer form an object of export. Mules are better fitted for the mountainous parts of the country, and in general use there. In the high grounds of Abruzzo and Calabria, cows, oxen, sheep, are reared in considerable quantities; while large droves of buffaloes range along the marshy tracts on the north-west coast. Of wild animals, the lynx or tiger-cat is found in the higher parts of the Appennine; the crested porcupine is said to be peculiar to the south of Italy; snakes and other reptiles are met with in the hot districts.

The unhappy circumstances of his political condition, the heaviness of taxation, the insecurity of property, which have acted so banefully on the Neapolitan husbandman, produce a similar effect on the merchant and manufacturer. The trade of Naples is mostly in the hands of British subjects, who, by a late treaty (1816), are put on a footing of equality with the natives The fabrics of the country are of little variety, and insignificant extent. Of the 8000 cwt. of silk annually produced here, about half is exported in a raw state, the remainder is prepared at home. Cotton, a production of the soil, is made into muslin, in a limited quantity, in the province of Otranto; coverlets are formed of it at Nardo and Galatona. Potteries exist in the capital, and at Teramo in Abruzzo Ultra: in the former are also some establishments of embroidery. The *liqueurs* and other confectionary of Naples are known in foreign countries. The exports, however, are chiefly confined to raw produce, oil, silk, wool, fruit; to which are added, in smaller quantities, cotton and wine. The imports are more diversified, consisting of sugar, coffee, and other groceries; woollens, linens, cotton goods, British or East Indian; with hardware, clocks, watches, household furniture, and large quantities of salted fish.

The latter article is indispensably requisite here, as in all countries professing the Catholic religion, and strictly conforming to their profession of it. Catholicism is the universal creed in Naples; and the people are devotedly attached to it. The only *dissenters* are a few miserable hordes of Albanians, whose ancestors sought refuge in the south of Italy from the oppressions of Mahomet II. during the fifteenth century. They still follow the Greek mode of worship, in a few villages, where they live distinguished for their uncultivation even among the peasantry of Naples.

The *revenue* and *forces* of Naples are small, and imperfectly known. Next to no provision is made for *educating* any considerable class of the community; and the general ignorance is proportionate to this inattention. The *government* is at present in a state of convulsion, or but momentary quiet, and cannot be described. We proceed to the *history*: our outline of it also must be brief.

Naples is said to have been founded by a colony of Athenians, at a period anterior to the building of Rome; and during the greatness of the Roman state it seems always to have been considered as a Greek city. When the Romans had extended their conquests to Samnium, the Neapolitans, from whom they met with no resistance, were received into the number of their allies, and permitted to retain their laws and municipal government.

In after times, when the taste for Grecian literature became general at Rome, Naples grew a favourite resort of the learned and the wealthy, and even in the declining days of the empire, is described by Cassiodorus as a rich and populous city, adorned with temples and the palaces of the wealthy, who resorted thither to enjoy its salubrious climate, and the luxuries with which it abounded.

On the fall of the Roman empire, Naples fell into the hands of the Goths, from whom it was recovered by Belisarius in 537, and although retaken by Totila in 545, was again delivered by Narses 555. After this period, Naples, and its surrounding territory continued to maintain its connection with the Grecian empire, and its chief magistrate, or duke, was appointed by the emperor or the exarch of Ravenna, his representative in Italy. After Ravenna was taken by the Lombards, however, the influence of the emperor in Naples, and the other Greek cities in Italy, gradually declined; in the 11th century, the duke, or master of the soldiers at Naples appears to have been elected by the people; and for a period of five hundred years, Naples, though continually obliged to maintain its independence against the Lombard dukes of Beneventum, whose territories surrounded it on all sides, had continued to retain its liberty. But the Lombards were not the only enemies who disturbed the repose of the south of Italy. In the 9th century, the Saracens, who possessed the opposite coasts of Africa, took several of the towns on the coast of Italy, and besieged the city of Gaeta.

These invaders were repelled by the valour of the Neapolitans, but their privateering vessels, which were then, as they are now, the pests of the Mediterranean, were so injurious to trade, that the republics of Naples, Gaeta, and Almalphi, were obliged, in their own defence, to devote much attention to their naval force; in which they attained to such a degree of superiority, that the Neapolitans were long considered the best seamen in Europe.

At length, these republics, which had so long defended themselves against such powerful enemies, were overwhelmed by the Normans, who made their first appearance as a band of adventurers in the pay of the prince of Salerno, about the time of the first crusade; but afterwards, assisted by successive reinforcements from Normandy, made themselves masters of Apulia, Calabria, and Sicily, and at length, under Roger II. took the city of Naples: and that prince, having received the title of king of the Two Sicilies from Pope Innocent II. who had become his prisoner, fixed his residence at Naples, which has ever since been the capital of the kingdom. For the history of Naples, after this, we refer our readers to the article Italy, with the general history of which Naples is intimately connected; and shall only say a few words respecting the late revolution in that country, an event which has so remarkably excited and disappointed the expectations or fears of the other nations of Europe.

At the period when the power of Napoleon was at its height in Naples, as well as in the rest of Europe, there still remained in that country many persons, who were indignant at the servile state of dependence to which that country, though possessing a nominal sovereign, was reduced. Of these persons, the late queen Caroline, wife of the present Ferdinand VII. whose restless spirit was always engaged in some intrigue for the recovery of Naples, determined to make use, and employed as her agent for this purpose, Cardinal Ruffo, who succeeded in organizing a secret association, the members of which were styled Calderari, whose secret object was the restoration of the ancient dynasty, and the pontifical power. Most of the members of this association were men of desperate fortunes, lazzaroni, and assassins, who were supplied with arms, and ready to take advantage of any political change or intestine tumult.

The death of queen Caroline, and the safe return of king Joachim to Naples, after the Russsian campaign, put an end to this confederacy, and most of its members were discovered and punished.

The severity of the conscription, and the other oppressive measures of the military despotism to which they were subjected, kept alive the spirit of discontent, and a new society was organized, resembling the former in its dislike to the present government, but professing also a general abhorrence to tyranny, and intolerance of every kind. This society was called the Carbonaria, or place where charcoal is prepared, and its members Carbonari, or coal-burners. Its separate meetings were styled barrache, or markets, and its principal lodge the alta boracha, or great market. Of the precise nature of the proceedings or doctrines inculcated at these places, it is impossible to speak, as the meetings, like those of free-masons, were secret; like free-masons, too, the members had mystical initiating rites, and veiled their lessons of union and virtue, as they termed them, under symbolical representations, and a jargon, understood only by the brethren. The most perfect equality was a leading principle of the sect; and it contained members of every rank and condition, from the noble to the lazzaroni. The influence of an association like this, under a government which repressed every open expression of popular feeling, may easily be conceived. It was soon felt and dreaded, and, during the absence of Joachim with the army, in 1813, his queen, who was left at the head of the regency, was led to take measures against them; and the king himself, whom the carbonari, after the first proceedings of the allied powers at the congress of Vienna had thrown some light on its real design, were willing to have supported against the Austrians, pursued the same policy.

In 1815, Murat was defeated, discrowned, and executed; Naples surrendered to a British squadron; and king Ferdinand, after an absence of nine years, returned in triumph to his capital. But the jubilee attending his arrival was of short duration. Ferdinand IV. was always a man of the weakest faculties, and his ignorance was extreme. Shooting pheasants,[*] not governing a kingdom, was his forte: and the carbonari, under his administration, had abundant cause and abundant means to propagate their feelings of dissatisfaction, and augment their numbers. The revolutions of Spain and of Portugal gave energy and form to their measures; the military became imbued with similar principles; and a simultaneous revolt of almost all his troops, in the end of 1820, compelled Ferdinand to resign, and the prince, his son, to sanction a form of government similar to that of Britain.

The Neapolitans assembled a parliament, and went forward rapidly in the work of legislation. The lovers of freedom began to hope; the lovers of quiet to fear: the Neapolitans disappointed both. Sicily, where one party was for an independent government, another for a continued junction with Naples, became a scene of horrid outrages, which ended in nothing; and the Italian part of the nation, who had thrown off the yoke so easily, took it on again with equal ease. The sovereigns of Russia, Austria, and Prussia, published manifestoes, and assembled at Laybach, to provide for what they considered the peace of Naples, and the safety of Europe. Their proceedings were looked upon with considerable diversity of opinion, in France and England; but neither of those courts felt it their duty to interfere. Ferdinand was invited to attend the conclave at Laybach: he returned with an Austrian army to escort him. The Neapolitan senators stormed and deprecated: their troops fled almost without a wound. Ferdinand was reinstated; the carbonari were banished or shot: and thus, what promised once to be a revolution, turned out to be a paltry tumult. The Austrian troops are long ago withdrawn; and all seems as it was at Naples. Discontent with their king, disdain for their countrymen, still rankle deeply in a few minds; but Naples has now been gathered into the great circle of interests which the northern sovereigns dispose of, and control, and its fate, and the changes it is destined to undergo, must for a time be regulated by the fate and the changes of Europe in general.

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[*] He used to inform his cousin of Spain regularly of his success in this vocation. The number of *braces* was pointedly recorded in the *despatches* of the royal sportsman; and he wrested from the pope a license to continue his destructive operations even on Sundays.

A conversation, in which Ferdinand was taking part, once happened to turn on the execution of Louis XVI., then a recent event. Some one remarked, that Louis' condemnation was the second crime of the kind which had occurred in Europe; the king eagerly inquired where or when was the first? The speaker, of course, answered that it was in England, and that Charles I. was the victim; whereupon his majesty rejoined with some heat: "No, Sir! you are misinformed: the English are too brave and loyal a people to be guilty of such a thing. Depend upon it, Sir, this is a mere tale, trumped up by the Jacobins of Paris, to excuse their own guilt: it may do very well to deceive the French, but *we* shall not be gulled by it, I hope."

NAPLES, the capital of the kingdom of the same name, is situated in latitute 40° 50′ 15″ N. and in longitude 14° 50′ 15″ east of Greenwich.

There is no city in Europe more distinguished for the beauty of its site. Its position is in the form of an amphitheatre on the shores of a bay, which seems as it were shut up by the island of Capri, which lies 17 miles to the south, and by those of Procida and Ischia. On the east, Vesuvius raises its insulated and fire-scathed summit, and at its feet lie the beautiful villages of Portici, and Torre del Greco. On the other side, is the hill of Posilipo, with the tombs of Virgil and Sannazarius. At a distance is seen the chain of the Appennines, from which a branch detaching itself runs to the south-west, surrounding Vesuvius, having its summits crowned with the villages of Castell a Mare, Massa, and Sorrento, the birth-place of Tasso. The city itself is seated on the slope of a range of beautiful hills, fronting the south and east, enjoying, at almost every point of view, the most varied and delightful prospects.

Its situation is even surpassed by its climate: its sky is ever pure and serene, its air free and salubrious, and its soil remarkably fertile. It is not then surprising that travellers should describe Naples with more than ordinary enthusiasm.

This situation, in which nature displays all her charms, this bright and cloudless atmosphere, inspire the heart with an unusual energy, and fill the soul with the vivid illusions of romance; surrounded every where by the most exquisite specimens of art, while listening to the notes of Pergolesi and Iommelli, or admiring the scenes which inspired the youthful muse of Tasso, the enraptured stranger catches as it were a portion of their spirit, and feels as if he trod a soil sacred to music and poesy.

These advantages have at all times made Naples a most desirable place of residence. During the time of the Romans, the shores of its bay were covered with their villas; and there are few of their poets who have not celebrated the beauties of Parthenope. In modern times, such has been the increase of inhabitants, that many of the villages which formerly surrounded the town, are now joined to it, and these suburbs now contain a much larger population than the ancient city itself. Naples was formerly divided into four parishes; but these, from the subdivisions occasioned by the increase of inhabitants, and the addition of the suburbs, had, in the year 1791, increased to the number of 48, and were supposed to contain a population of above 450,000 souls, independently of the adjacent villages, the number of whose inhabitants was computed, at the same period, to amount to 135,000.

The appearance of the interior of Naples is in general pleasing; the principal streets are wide and well built, and the public edifices so lofty and solid, as to give a general air of grandeur to the city. Their magnificence, however, chiefly consists in their magnitude: they want simplicity and unity of design, and present a confusion of almost every order of architecture; and the paintings, marbles, and other decorations, with which they are enriched, are seldom judiciously placed, and, even when best disposed, are scattered around with a profusion which destroys their effect.

The buildings which occur in the greatest number, are churches and monasteries, of which our limits will only permit us to enumerate a few of the most remarkable.

The cathedral is founded on the site of two ancient temples, one of which was dedicated to Neptune, and the other to Apollo. It is the largest church in Naples, and lays claim to very great antiquity. It was rebuilt or enlarged by Charles I., and finished by Charles II. of Anjou; but having been destroyed by an earthquake in 1496, it was again repaired by king Alfonso of Arragon. The structure had been originally Gothic, but has been much disfigured by the injudicious repairs and alterations, in different styles of architecture, in later times. More than a hundred pillars of oriental granite, which formerly supported the Temple of Neptune, are still in the cathedral, but have been covered with stucco by the barbarous taste of one of the archbishops. This church contains the tombs of Charles of Anjou, of Pope Innocent XII., and of Andrew, the husband of queen Jane I., who was strangled at Aversa, by her orders, or with her connivance.

The many chapels attached to the cathedral are extremely rich in statues of silver, gilded roofs, &c. and some are adorned with the still more valuable productions of Dominichino and Guido. In a subterraneous chapel, under the choir, is said to be deposited the body of St. Januarius, and here, to the disgrace of the Romish church, the celebrated miracle of the liquefaction of his blood is still exhibited by the priests, an imposture which even Eustace, the zealous defender of the Catholic superstition, has the candour to acknowledge.

The church of the Holy Apostles, situated on the ruins of a temple of Mercury, is one of the richest and most beautiful in Italy. In the library of the monastery, of which this church is a part, there is a valuable collection of manuscripts, among which are those of Tasso.

Naples also contains several literary establishments worthy of notice. The university was founded in 1224. The edifice is on a large scale; and though still incomplete, is elegant and commodious. It has a library of 90,000 volumes, several ancient manuscripts, and specimens of the earliest attempts at printing. It has also a cabinet of the remains found at Herculaneum; and a collection of Etruscan vases. The number of students, however, is small; and the fame of this seminary, as a seat of learning, has never extended beyond the boundaries of the kingdom. Besides the university, there is a royal military school in Naples, a royal naval school, and a college for the instruction of young Chinese and Japanese. There are likewise four public libraries, an observatory, and a botanical garden.

The hospitals *Degli Incurabili* and *Della Annunziata* are the richest and most extensive of the charitable foundations. The former is intended for the benefit of sick persons in general; the latter is destined to receive foundlings and penitent females; each accommodates from 1500 to 2000 inmates. Five additional hospitals of smaller note; above thirty schools in which poor children of both sexes are boarded, taught to read and write, and instructed in music, or some mechanical trade; five pawn-banks for the use of the industrious indigent,—must also be reckoned among the public charities of Naples, most of which are said to be well endowed and judiciously managed.

Naples has extensive manufactures of silk; small ones of stockings, gloves, lace, and cotton. It makes fire-arms, china-ware, glass; its musical instruments and cabinet-work, and toys formed of lava, are well known. The exports and imports of Naples are various in kind, but inconsiderable in quantity; they pass mostly in foreign vessels. Corn, oil, wine, cotton, silk, wool, the products of its soil, form the principal exports: in return for them it receives jewellery and linens from France; fine woollens, colonial goods, and salted fish, from England. From the Baltic it imports hides; from Spain and Portugal drugs, dye-stuffs, tobacco, cocoa. The trade is principally managed by British merchants and ship-owners.

The population of Naples amounts at present to 330 000, of whom, according to a late survey, 155,000 are males, 175,000 females; the births being annually about 12,500, the deaths nearly equal. Their character does not stand high among other nations. A traveller from the north of Europe is shocked at the ignorance, frivolity, and dissipation of the higher ranks; disgusted at the indolence and superstition of the lower. His attention is awakened, at the same time, as keenly, and far more agreeably, by various peculiarities in the habits of the latter. A mild climate exalts the susceptibility, quickens the imagination of the people, and gives an air of picturesque extravagance to many of their proceedings. Owing to the same cause, too, an unusual proportion of their time is spent in the open air; and many of the operations which, in other countries, take place within doors, are here exposed to public view. Even their cookery is generally performed on the street. The *Lazzaroni* constitute a distinct class of the populace, peculiar to Naples. Nearly 30,000 of them crowd the porticoes of the city, or the caves in the neighbouring beach. They have no house, no trade; some of them have no name. They perform miscellaneous services of all kinds for hire; they beg, and occasionally steal. See Eustace's *Classical Tour*.

NATCHEZ, capital and chief town of the state of Mississippi, stands on the left bank of the Mississippi river, at North Lat. 31° 33′, and 91° 30′ West of Greenwich, or 14° 30′ West from Washington city.

Natchez is formed by the lower and upper towns; the former situated on the margin of the Mississippi river, and the latter upon the high country formed by the bluffs. It is, compared with its population, one of the most commercial towns in the United States, with a very fertile and well cultivated country in its vicinity. The city is laid out in form of a parallelogram, the streets crossing each other at right angles. The ground upon which the town is built is rolling, without the admixture of a stone, and scarcely a pebble. The inhabitants are supplied with water from wells, or from the Mississippi river. Natchez contains one bank, a state house, court house, a Roman Catholic chapel, and some other places of public worship, with a few schools.

The population, in 1820, stood as follows: free males 900, free females 548; male slaves 298, female slaves 356; free blacks and people of colour, males 130, females 42, and strangers not naturalized, 42: total population, 2186.

This city is governed by a mayor, aldermen, and city council, with the county magistrates, who have concurrent jurisdiction within the incorporated limits with the aldermen.

Natchez stands 322 miles above New Orleans, by the windings of the Mississippi river, and 427 above the mouth of that stream. By the road from Natchez to New Orleans, by the route of lake Pontchartrain, the distance between the two cities is only 156 miles.

Natchez is 669 miles below the mouth of the Ohio, 846 below St. Louis, and 1613 below Pittsburgh.

The site of the upper and main part of Natchez is about 100 feet above the level of high water mark in the Mississippi river. This city rose upon the ruins of old fort Rosalie. The adjacent country was settled as a part of Louisiana, by the French, in 1718, and, in a few years, upwards of one hundred families had been induced, from the healthy nature of the country, fertility of the soil, and mild character of the natives, to establish themselves in the neighbourhood. Provoked by the insults and exactions of the French commandant, the Indians, in 1729, formed a plot for the purpose, and falling upon the whites by surprise, a general massacre ensued; only two or three persons found means to escape. The country continued again unsettled by the whites about thirty years, and indeed no considerable attempts were made to re-establish the place until after the beginning of the revolutionary war. Since that period Natchez has gradually rose into a very prosperous though small city. In 1800, the first legislative assembly for the then Mississippi territory, met at Natchez. Since the latter epoch, it has been alternately the seat of government for the territory, and, since the formation of the state of Mississippi, of that commonwealth. It is now the seat of government; but, by a recent law of the state, the capital is to be permanently fixed upon the Pearl river.

NATCHITOCHES, a parish of Louisiana, forming the north-west angle of that state. This parish extends over upwards of 10,000 square miles, chiefly barren pine woods. Red river winds through it diagonally, from north-west to south-east. Most of the fertile arable soil of the parish lies along Red river, the alluvion of which stream is remarkable for the production of excellent cotton and tobacco. Population, in 1820, 7486.

NATCHITOCHES, capital of the parish of the same name, stands upon the right or west bank of Red river, at North Lat. 31° 46′, West Long. from Greenwich 93° 10′; or, 16° 10′ West from Washington city. The houses are chiefly contained in one street, running parallel to the river. The number of inhabitants about 600, or about one twelfth part of that of the whole parish.

Natchitoches is situated 407 miles above New Orleans, by water, and 356 by land, by the route of Opelousas, Attacapas, and Lafourche.

DARBY.

NATIONAL DEBT. See DEBT.

NATOLIA, or ANATOLIA, is a province of Asiatic Turkey, bounded on the south and west by the Mediterranean, on the north by the Black Sea, and on the east by Caramania. It stretches about 400 miles from east to north, and 350 from north to south.

The soil of the province, which is fertile, produces corn, tobacco, and various fruits, and silk and cotton are also among the productions of the country. It carries on a considerable trade in leather, drugs, cotton, and silk. The inhabitants are chiefly Mahometans. The Christians, who are numerous, are tributary to the Porte.

NATRON. See MINERALOGY, and the *Memoirs of the Cambridge Philosophical Society*, vol. i.

NATURAL HISTORY.

NATURAL HISTORY embraces a very extensive field of human knowledge. It is, indeed, somewhat difficult to determine the objects which it legitimately comprehends, as the notions generally entertained on the subject are exceedingly vague and indefinite. It appears to embrace a description of all the phenomena presented by the material world—of the forms and changes of the heavenly bodies, and the objects which present themselves on the earth. It may thus be considered as paving the way for the researches of the Natural Philosopher, the chemist, and the physiologist, by stating the conditions of the different problems which each, in his respective department, is called upon to resolve. The naturalist, however, does not content himself with a mere description of the appearances of nature. He attempts to classify the phenomena, and, availing himself of the discoveries in those sciences to which his labours have paved the way, he ventures to trace and explain their mutual dependence. He thus endeavours to form what has been termed a SYSTEM OF NATURE, in which all the objects which present themselves to our notice are designated by appropriate names, distinguished by particular characters, and have their various changes and mutual relations distinctly determined. Natural history may, therefore, be considered as the art of ascertaining the names of objects, and the science of determining their habitudes and relations. It is intended, in this article, to give a brief summary of its leading divisions, and to recommend it as an agreeable and useful employment of the human mind.

The objects which present themselves to our notice on *this globe*, (for the naturalist has abandoned the celestial phenomena to the astronomer,) though differing in form, texture, and motions, range themselves under two very distinct heads, termed the *inorganic* and *organized*. The division is obvious, and has been universally recognised. The *chain of being*, which poets and philosophers have talked so much about, by which minerals are connected with vegetables, these last with animals, and man with his Maker, is a fiction of the imagination, and the offspring of ignorance. The reader will find a demonstration of this statement in Dr. Fleming's "*Philosophy of Zoology*," vol. i. p. 3—7.

CHAP. I.

ON THE NATURAL HISTORY OF INORGANIC BODIES.

The inorganic kingdom presents to the naturalist three divisions of objects of vast importance to our existence and comfort, which correspond with the ancient distribution of inanimate bodies, under the terms air, water, and earth.

SECT. I. *Natural History of the Atmosphere.*

The natural history of the atmosphere is usually studied in connection with the truths of natural philosophy and chemistry, under the term *Meteorology*. This is a branch of knowledge which attracted the attention of mankind at a very early period of society. Many curious remarks on the subject occur in the Greek and Roman writers. But it was not until the discovery of the barometer and thermometer, in the seventeenth century, that any accurate observation could be made, or general laws determined. By means of the former instrument, the weight or pressure of the atmosphere has been determined, together with some of the causes which influence its diminution and increase, and the signs by which these variations are accompanied. The latter instrument has pointed out the changes which take place in the temperature of the atmosphere, according as these depend on the seasons, the elevation above the level of the sea, and the actions of currents. It has enabled us to ascertain the degree of heat best suited for the growth of animals and vegetables, and those places which are most salutary for valetudinary persons, where the range of temperature is confined. The moisture of the atmosphere can scarcely be said to have been investigated, owing to the imperfection of the instruments employed. Even with regard to the pressure and temperature of the atmosphere, many things yet remain to be determined; such as the origin of the disturbing causes of the former, and the inflexions in the isothermal lines.

The various appearances which the atmosphere exhibits at different times, and the changes which these indicate, have not passed unobserved.

The history of *winds* is a subject of very great interest, especially when we attempt to ascertain their prevailing direction, and the periods of their duration, for the purpose of furnishing the sailor with a knowledge of his dangers, and of regulating the laws of insurance.

The natural history of *rain* can scarcely be said to have hitherto been studied with care. The appearances of the sky which precede rain were never described with accuracy, until the nomenclature of clouds by Howard; and since the introduction of definite language, few have studied the conditions of the phenomena. A careful examination of the circumstances under which dew is formed, enabled Wells to refer its formation to the radiation of heat from the earth's surface. It is more difficult to account for the production of fogs, hail, and snow.

The luminous meteors, including the falling stars, the northern lights and lightning, have arrested the attention of all classes of observers. The naturalist, however, was far from successful in observing the appearances of these phenomena, until the electrician furnished him with an explanation of their origin.

The natural historian, in reference to atmospherical phenomena, is likewise called upon to examine the condition of those stones, which, at different periods, and in different countries, have fallen from the air. Until these conditions are satisfactorily ascertained, including the appearances of the sky previous to their fall, the direction in which they descend, and their temperature when they reach the earth, it will be difficult to determine their origin.

These various changes which take place in the atmosphere, are accompanied by corresponding changes in other inanimate, as well as animated beings. It is a useful and pleasing employment to investigate these concomitant phenomena, and to be able to predict the changes in the weather, from the peculiar appearances presented by plants or animals, and by the atmosphere itself. In this department of the subject, the number of well established facts is, perhaps, greater than is generally supposed.

SECT. II. *Natural History of the Waters.*

The natural history of the waters is usually termed Hydrography, or the science which explains the phenomena, Hydrostatics or Hydrodynamics. In the investigation of this subject, it is necessary to trace the circulation of water throughout the globe from the springs at which it issues, and the rivers and lakes through which it flows, till it reaches its destination in the great basin of the ocean.

The springs, in reference to the nature of the water, are either nearly pure, or so much contaminated by various substances held in solution, as to obtain the denomination of *mineral waters*. The temperature of springs deserve attention, as being, in general, similar to the mean temperature of the air of the district in which they are situated. The situation and duration of springs claim the notice of the agriculturist, as indicating the rules to be observed in the practice of draining.

The natural history of rivers includes the character of their waters, their channel, and the features of the banks, the length of their course, and the obstacles which they overcome, and the materials which they transport. A knowledge of these circumstances suggests the proper methods to be pursued in embanking rivers and clearing or deepening their channel. It likewise points out to us the origin of many of the appearances which the earth's surface presents, and thus furnishes a solution of some of the most difficult problems in geology.

The history of lakes is still involved in great obscurity. Concerning the origin of these beds, nothing satisfactory has hitherto been advanced. The methods, however, employed by nature to fill them up, and to produce layers of peat and marl, have been studied with care, and useful inferences drawn from them by the agriculturist and geologist. The knowledge of the depth and temperature of lakes would enable us to stock them with suitable plants and fish, and thus convert extensive sheets of watery wastes into store-houses of food. How much remains to be done in this department of rural economy in Great Britain and Ireland?

The *Ocean*, that great reservoir of the waters of the globe, exhibits, to the historian of nature, ample materials for the employment of his powers of observation and description. The field indeed is immense. The motions of the sea, its depth, temperature, and saltness, are all calculated to provoke inquiry, nor are those efforts less meritorious, which are made for the purpose of determining the changes which have taken place in its level, its destructive influence on its coasts, and the origin of the sand we observe accumulated on its shores. The inequalities of the bed of the ocean, though eagerly inquired after by the mariner, have been but imperfectly explored, as the plumb line is the only instrument which can be employed in surveying them.

SECT. III. *Natural History of the Earth.*

The history of the earth, in so far as the naturalist is concerned, is usually termed MINERALOGY. The first object of this science is, to determine the characters of the different substances of which the crust of the earth is composed, with the view of bestowing upon them appropriate names, and giving them an accurate classification. Many of these substances exhibit regular geometrical forms, which have been examined with considerable care, and the results now constitute the science of CRYSTALLOGRAPHY. The naturalist ought next to proceed in the examination of the manner in which mineral species are associated, the relations which they exhibit to one another, and the beds or strata which result from their union. These beds or strata exhibit determinate relations, in the order of their superposition, in their extent and inclination—in their imbedded minerals and organic remains. These last are generally termed *petrifactions*, and the peculiar characters of their condition have made us acquainted with those vast revolutions, which have convulsed this globe, disturbed its solid beds, and entombed myriads of plants and animals, which flourished prior to any human record, which have left no descendants, and no monument to record the nature of the catastrophe which completed their extinction.

There are other circumstances connected with the natural history of the earth, which likewise merit attentive consideration. It is exceedingly irregular in appearance, rising into lofty mountains, stretching out into extended plains, or intersected by valleys and ravines. A variety of causes are operating at present in increasing or diminishing the inequalities. A careful examination of these, is the only method of arriving at a knowledge of the circumstances which originally were in operation.

The mind of man never rests satisfied with the plain truths which it is the business of the natural historian to explore and communicate. It is ever disposed to speculate and explain, and is frequently better pleased with the representations of the imagination than the generalization of the reasoning powers. These remarks are justified by the speculations of geologists. Multitudes who have not examined the actual condition of the earth, the existing arrangements of its beds, and the mutual relations and habitudes of the minerals which compose them, and the systematical characters of petrifactions, and their physical and geographical distribution, nevertheless venture to offer explanations of appearances which they have not studied, and assign causes for the production of phenomena, which, had they operated, must have produced very different results. These presumptuous attempts have been dignified with the name of *theories of earth*. Hitherto, however, they have borne the same relation to natural history, and geology, properly so called, as works of fiction do to genuine history and science. Both serve the same purpose—amusement; both are the offspring of the same faculty—the imagination.

It would serve many useful purposes were the term *geognosy* limited to express our knowledge of the *actual condition* of the earth, without a reference to theory, or to include nothing more than the natural history of minerals. Geognosy would in that case be occupied in preparing the mind for the application of the discoveries of science to the explanation of the phenomena, and would constitute the safe road to *Geology*. This last mentioned department of human knowledge has advanced with a slow and unsteady pace. Attempting to arrive at its desirable objects without traversing the fields of geognosy, its votaries have bewildered themselves, and have drawn down no inconsiderable share of popular derision. Eagerly attempting to account for the inclined position and other irregularities of the older rocks, they have refused to investigate similar phenomena which present themselves in every sand hill. They have exerted themselves, without success, to explain the appearances of a coal-field, because they have overlooked similar appearances more recent and intelligible, exhibited by every peat-moss seated in a valley. The geologist, however, has made at least one important step in the inquiry, by having determined the density of the earth. It is lightest at the surface, and this arrangement appears to have been produced by the same cause which gives to the atmosphere its increased rarity as we ascend. Geologists have been less fortunate in their attempts to determine the figure of the earth. Anxious to establish its form as a spheroid of equilibrium, they have tried in vain to reconcile the opposing results of trigonometrical measurements, and have shut their eyes against the indications of its irregularity, exhibited by the elevation of the mountains, and which might have been inferred from the extensive revolutions which it has undergone. The earth is not yet old enough to be regular in its form.

Having thus marked the peculiar objects of the naturalist in reference to inorganic bodies, and having delineated the leading features of the sciences of meteorology, hydrography, and mineralogy, we come now to consider natural history as occupied with living bodies.

CHAP. II.

ON THE NATURAL HISTORY OF ORGANIZED BODIES.

Organized bodies are usually distributed into two great groups or kingdoms, in one of which plants, and in the other animals, are included.

SECT. I. *Natural History of Plants.*

This department of knowledge is termed botany. Those who have cultivated this pleasing study have pursued very different methods of investigation, and have arrived at very different results. One class of observers have devoted their labours to the *naming* of plants, and to the discovery of those marks by which they may be recognised in their arbitrary arrangements. The followers of this humble occupation attempt to establish what is termed the *artificial method*. Another class of observers, with more enlightened views, attend to all the characters of every organ, and leave no form or change unexplored. They examine the seed, and its mode of germination; the root, and the qualities by which it is fitted to act as an organ of nutrition and support; the stem, its peculiar structure, and the origin and position of its branches; the leaves, their peculiar forms, position, and duration; the flowers, the structure of their protecting calyx, and delicate corolla; the fruit, the period of its ripening, and the mode in which the seeds are disseminated. Botanists who attend to all these characters, and found their systematical arrangements in reference to the whole, attempt to introduce what has been termed the *natural* method. The followers of this method prepare the way for the *physiologist*, who attempts to explain the uses of the different organs, and by experiment to establish the truth of his opinions.

The botanist does not occupy himself exclusively with studying the forms of the various organs of plants. He examines their condition in reference to their physical and geographical distribution, for the purpose of discovering the circumstances which regulate the translation and naturalization of plants.

SECT. II. *Natural History of Animals.*

Zoology is the term employed to designate the natural history of animals. There is in this science, likewise, an artificial and a natural method of arrangement, and a knowledge of the form and structure of the various organs prepared for the higher disquisitions of physiology. But the zoologist is called upon to examine appearances which do not present themselves to the botanist. Animals have not only life, but sensation; and the actions to which this last faculty gives rise are exceedingly varied and complicated. To a want of acquaintance with these, we may trace a great deal of that unprofitable speculation indulged in by the moral philosopher, about the difference between the reason of man and the instinct of brutes. In order to solve this curious question, it is necessary to be acquainted with life, and its various phenomena, or, in other words, with the natural history of the *actions* of animals. Many philosophers have overlooked this step of the process, and have accordingly drawn conclusions remote from truth.

In attending to the physical and geographical distribution of animals—the zoologist becomes acquainted with those species which might be rendered useful to man, by being reduced from a wild to a domesticated state, and with those which might, with advantage, be translated from foreign countries into our own.

It is generally acknowledged that, in the study of natural history, more information can be gained by the eye, than can be communicated to the ear. Hence, wherever the science has been cultivated, collections of natural objects have been formed, to aid the memory, and supply the defects of descriptive language. Such collections are usually termed MUSEUMS.

The productions of the mineral kingdom are collected with the greatest care. There is little difficulty in preparing them, and they are not liable to decay. A mineralogical museum ought to contain specimens of simple minerals—of rocks—and of petrifactions, disposed in such a manner as to elucidate their systematical arrangement, and prepare for the application of the doctrines of geology.

A collection of plants may be preserved either in a living or dead state. When in the former, it is termed a BOTANIC GARDEN. A well regulated garden of this kind is eminently calculated to excite a zeal for the study of nature. When we view the productions of distant countries, and of different climates, flourishing in healthful luxuriance around us, we feel conscious of the dignity of our nature, and willingly allow the pleasant sensations which have been excited to be elevated by the reflection, that all those objects have been brought together for scientific, and therefore useful purposes.

When plants are preserved in a dried state, the collection is termed a Herbarium. A museum of this kind is indispensably necessary. Plants have particular seasons in which they vegetate and unfold their organs, and consequently can only be examined at those intervals, frequently short and distant. But when plants are well preserved in an herbarium, they are accessible at all times, and greatly aid the student in his knowledge of species.

Collections illustrative of the natural history of the animal kingdom are likewise exhibited to us, either in a living or dead state. A collection of live animals, for want of a more appropriate term, is called a *Menagerie*, and enables the student not only to observe their forms, but their motions and instincts. Such an establishment is necessarily very expensive, and is seldom attempted but in national establishments, or by individuals for the sake of gain. It in general labours under a defect of cleanliness, which no care on the part of the keepers can entirely remove.

Many animals, such as quadrupeds, birds, and insects, can be easily preserved in a dried state, so as to exhibit the forms and colours of the living subject. Such a collection is admirably calculated to awaken an interest in the study, and facilitate the attempts of the naturalist to construct a systematical arrangement.

The science of natural history must have occupied the attention of our race in all ages, and in every period of civilization, as we depend on the objects which surround us for food, shelter, and amusement. The savage is compelled to study the manners of those animals he pursues in the chase, the haunts which they frequent, the seasons of the year in which they are most abundant, or best suited to his purpose. The same necessity prompts us to study likewise the habits of those plants which furnish the most palatable food and efficacious medicine; the most suitable wood for making an arrow or spear; and the most deadly juice in which to dip them. Man, even in the early stages of civilization, is also urged to examine the rocks in search of flints with which to point his dart, or stones to form his hatchet.

But the importance of natural history is more sensibly felt as man advances from the savage to the pastoral or commercial state. When he begins to rear animals, that he may drink their milk, clothe himself with their skin, and feed on their flesh, he must study their history, for the purpose of providing them with suitable food and shelter, and guarding them from the attacks of their foes. In like manner, when he sows grain for his subsistence, and plants the sugar cane—the cotton tree, or the potatoe, he must attend to the peculiar soil each plant requires, the seasons of sowing and reaping, the weeds which obstruct their growth, and the blasts which wither them. When he descends into the bowels of the earth in search of treasure, he is induced to study the nature and the relations of those rocks which are most productive in the objects of his pursuit, and to ascertain those ores which yield the purest metals.

As the natural historian is exclusively occupied with observation, it is necessary that he leave the closet, and explore the characters of the different creatures of this globe in their ordinary situations, and mark their changes when beyond the sphere of human influence. He will often find himself anticipated by the discoveries of the huntsman, the fisher, the farmer, or the miner. These are all practical naturalists, and, in their respective departments, frequently discover both extensive and accurate information. Could we, therefore, behold the practical observer studying the rules of the science—and the closet naturalist respecting his discoveries, and giving them a suitable arrangement, the whole subject would by degrees assume a new form, and facts would multiply under the banners of public confidence. The scientific naturalist, acquainted with the rules of system, and in league with the daily observer, would be able by his instructions to extend our dominion over the creatures of this globe, and increase the comforts of society.

This department of human knowledge appears so interesting and important, as to deserve a place in every system of education, and ought to be taught, not in colleges merely, but in every parochial school. Information on this subject, thus obtained, would prove highly useful in after life, and infinitely more valuable than many of those branches of ornamental knowledge in which children are initiated. We are far from undervaluing the languages of Greece and Rome, those valued stores of poetry, though not of science,—we are equally far from undervaluing the genteel accomplishments of music, dancing, or riding—but we are confident, that, were the advantages to be derived from the study of natural history fairly placed in competition with any, or with all of these, it would probably be allowed to occupy a more exalted place in public opinion than it has hitherto been suffered to possess. At present the pursuits of the naturalist are often sneered at, and considered as a degrading employment to a cultivated mind. We, in our turn, deplore popular ignorance, and regard every object which the Deity has created as worthy of our notice—whether it be the mite or the elephant, the hyssop on the wall or the cedar of Lebanon, the dull clay or the glittering marble.

The following is a List of the Articles of Natural History as given in this work, arranged according to the divisions in the present article:

Chap. I. Sect. I.—Atmosphere.
Aurora Borealis.
Cold.
Halo.
Hygrometry.
Meteorite.
Meteorology.
Sect. II.—Mineral Waters.
Physical Geography.
Ice.
Sect. III.—Chrystallography.
Diamond.
Mineralogy.
Petrifactions.
Mines of Coal.
Theory of the Earth.
Chap. II. Sect. I.—Botany.
Filices.
Fuci.
Fungi.
Horticulture.
Lichen.
Chap. II. Sect. I.—Musci.
Vegetable Physiology.
Sect. II.—Amphibia.
Anatomy, Comparative.
Animalcule.
Animal Flower.

Cetology.
Entomology.
Conchology.
Crustaceology.
Hatching.
Herpetology.
Hybernation of Animals.
Ichthyology.
Insecta.
Mazology.
Mollusca.
Ophiology.
Ornithology.
Vermes.
Zoophytes.

Natural Philosophy, or Physics, as it is called by continental writers, is that branch of knowledge which treats of the action of natural bodies upon one another, when that action is not accompanied by any permanent change in their internal condition.

Natural Philosophy may be divided into twelve subdivisions:

I. *DYNAMICS.*

1. Dynamics,
2. Mechanics,
3. Hydrodynamics,
4. Pneumatics,
5. Acoustics,
6. Astronomy,
7. Optics,
8. Electricity,
9. Galvanism,
10. Magnetism,
11. Meteorology.

The subject of Dynamics, which comprehends the laws of motion, the doctrine of forces, and the motions of projectiles, will be found treated at considerable length under our articles Dynamics and Gunnery; and in the article Mathematics, the history of some of the most important problems will be found.

Such of our readers as wish to study the subject more profoundly, and at greater length, may consult, Hermanni *Phoronomia*.—D'Alembert's *Traité de Dynamique*.—Dr. Robison's *System of Natural Philosophy*, Vol. I. articles Dynamics and Projectiles.—Poisson's *Traité de Mecanique*.—Bridge's *Mechanics, &c.*

II. *MECHANICS.*

Mechanics is that department of Natural Philosophy which treats of the laws of the equilibrium and motion of solid bodies; of the forces by which bodies may be made to act upon one another; and on the means of employing them so as to overcome other forces which are more powerful. The history and general principles of mechanics have been fully treated under the head of Mechanics; and the subject of *Practical Mechanics* has been considered at great length in the same article. References to various other articles in this work, giving an account of machinery for different purposes in the arts, will be found under the *General Arrangement of Machines* which follows the article Mechanics. See also Carpentry and Joinery.

III. *HYDRODYNAMICS.*

Hydrodynamics is that branch of science which embraces the phenomena exhibited by water and other fluids, whether they are at rest or in motion. It is generally divided into Hydrostatics and Hydraulics, the former of which treats of the pressure, equilibrium, and cohesion of fluids; and the latter, of their motion, the resistance which they oppose to moving bodies, and the different machines in which fluids are the principal agent.

Under the article Hydrodynamics, we have given at great length the history and principles of the science, and have dwelt particularly on those practical branches which are intimately connected with civil engineering, and of such extensive application to the purposes of ordinary life.

IV. *PNEUMATICS.*

Pneumatics is that department of Natural Philosophy which treats of the pressure and equilibrium of elastic fluids, such as air, and of the machines in which these fluids are the chief agent.

Our articles, Aeronautics, Anemometer, Diving Bell, Blowing-Engine, Blow Pipes, contain practical details connected with pneumatics; but the history and principles of the science will be fully detailed under the general article Pneumatics.

V. *ACOUSTICS.*

Acoustics, or that branch of Natural Philosophy which treats of the nature and laws of sound, has been treated at some length in the article Acoustics.

Under the articles Æolian Harp, Echo, Harmonics, Music, Organ, &c. are given many details connected with this science.

VI. *ASTRONOMY.*

Astronomy, or the science which explains the nature and motions of the planets, comets, and fixed stars, the various phenomena which these bodies exhibit, and the laws by which their motions are regulated, has been fully and popularly treated in our article Astronomy.

Under the articles Aberration, Attraction of Mountains, Circle, Dialling, Graduation, Heliostate, Micrometer, Observatory, Orrery, Quadrant, and Telescope, the reader will find many details connected with the practical part of the science.

VII. *OPTICS.*

Optics is that science which treats of the nature and properties of light, and of the changes which it experiences either in its qualities, or in its direction, when transmitted through bodies; when reflected from their surface; or when passing by them at a small distance.

The history and principles of this science, and the description of optical instruments, will be fully treated in a subsequent part of this volume. Under our articles Accidental Colours, Achromatic Telescopes, Burning Instruments, Camera Lucida, Microscope and Telescope, the reader will find several interesting details, which could not be properly introduced under the general article.

VIII. *ELECTRICITY.*

Electricity is that branch of Natural Philosophy which treats of the nature and effect of that power which is developed by the friction of amber, glass, and other substances, and of the numerous and diversified phenomena, which, though produced in a different way, appear to be the effect of the same power. It is fully and popularly treated in the article Electricity.

The recent discoveries of M. M. Oersted, Ampere, Sir H. Davy, and others, respecting the connection of electricity and magnetism, will be given in a future article.

IX. *GALVANISM.*

Galvanism is that branch of Natural Philosophy which treats of a series of electrical phenomena developed without the aid of friction, and where a chemical action is perceived to take place between some of the bodies employed.

The history and principles of this new science are fully detailed in the article GALVANISM.

X. *MAGNETISM.*

Magnetism is that branch of science which treats of the nature and laws of the invisible forces, with which certain ores of iron attract to themselves pieces of iron that are brought near them.

The phenomena of natural and artificial magnets, and the subject of the earth's magnetism, will be found fully treated in the articles MAGNETISM and VARIATION of Needle.

XI. *METEOROLOGY.*

Meteorology is that branch of science which treats of the phenomena of the atmosphere, and describes the different instruments which are used for observing and measuring the changes which are constantly going on in it.

In the articles ANEMOMETER, AURORA BOREALIS, BAROMETER, ELECTRICITY, HALO, HYGROMETER, METEORITE, THERMOMETER, will be found much practical information on this subject, and the general principles of the science will be found under the article METEOROLOGY.

NAVAL ARCHITECTURE. See SHIP BUILDING.

NAVARRE, a province of Spain, bounded by the Pyrences on the north-east, by Arragon on the south and east, Old Castile on the south-west, and Biscay on the north-west. Its figure is irregularly quadrilateral, being about 18 leagues broad from east to west, and 14 from north to south. The principal valleys, which are very fertile, are those of Roncevaux, Lescou, Baston, and Roncal. The chief productions of the province are wheat, rye, barley, maize, beans, wine, oil, and hemp. The best wines are those of Tudela. The manufactures consist of brandy, of which there are distilleries at Estella, Fuente de la Reyna, and Sanguesa; cloth, which is made at Tudela and other places, soap, tiles, bricks, and pottery. Near Eguy there is a royal manufactory for cast iron, bombs and balls; and at Corella there is a manufactory of Spanish liquorice, indurated from the juice of the tree, and exported in great quantities to the north of Europe. There is a copper mine near Pampeluna; and a mine of rock salt, abounding with layers of gypsum, near Valtierra. Navarre has 2 bishoprics, 2 cathedrals and 15 collegiate chapters, 753 parishes, 70 religious houses, 12 hospitals, 1 university, 4 colleges, 9 cities, 154 towns, and 638 villages. Its population, about the end of the last century, was about 287,382, of which there were 753 parish priests, 1166 secular priests, 1120 monks, 510 nuns, 13,054 nobles, 172 writers, 1163 students, and 9910 servants. The trade of Navarre is confined solely to imports. Pampeluna is the capital of the province. See Laborde's *View of Spain*, vol. ii. p. 311.

NAVIGATION.

NAVIGATION, used in its most general acceptation, is the art of constructing ships, as well as of manœuvring them at sea, and guiding them, by the deductions of mathematical science, from one port to another.

This art, of so much importance in the present state of society, may be regarded under several aspects, very different from one another. In one sense it may be viewed as including the art of constructing ships of the most perfect form, for the purpose of being conducted with safety and expedition across the ocean: this branch of it is usually called *ship-building*, and we must refer to that article for the full elucidation of its principles. In another sense it may be regarded as the art of regulating the motion of this noble machine by mechanical contrivances, so as to employ with the utmost advantage the powerful agents which nature has presented for transporting it from place to place. This department of navigation constitutes *seamanship*, under which may be included, not only the management of a ship in ordinary circumstances, but also the manœuvring her in the face of an enemy, either for the purpose of giving battle, or avoiding an unequal conflict. See *Inland* NAVIGATION, SEAMANSHIP, SHIPBUILDING, and *Naval* TACTICS. Lastly, it is the art of conducting a ship from one port to another, so far as depends on the direction and length of the tract which she ought to pursue; and of finding, when necessary, her geographical position on the surface of the ocean. It is this branch of the subject which we propose to consider under the present article.

Navigation, in the restricted sense we have attached to the term, may be said to be a branch of geography and astronomy, inasmuch as it not only borrows from these sciences its leading principles, but depends, for a detailed illustration of its various parts, on the practical applications of which they are susceptible. In the short view, therefore, which we mean to give of the history of navigation, we shall confine ourselves entirely to an account of the progress of the art, so far as its improvement has been owing to the assistance which it has received from geography and astronomy, aided by the light of geometry; referring for the history of maritime discoveries to the article GEOGRAPHY.

While the practice of navigation was in a state of infancy, it neither required nor admitted the application of refined principles; for until the invention of the mariner's compass no voyage could be undertaken, unless such as might be accomplished by creeping slowly along the coast, exposed to all the dangers and obstructions of so circuitous a course. That valuable instrument, which seems to have been first used for nautical purposes about the beginning of the fourteenth century, gave a new impulse to maritime enterprise, and changed in a short time the entire character of navigation. Guided by this faithful monitor, the mariner no longer confined his tract within a limited distance from the shore, but ventured boldly into the ocean, and explored his way in the darkest night, and surrounded by the most obscured sky, with a confidence and a precision hitherto unknown.

The property which the magnet possesses of attracting iron was known to the Greeks from the days of Thales;[*] and the Chinese are said to have been acquainted with the fact upwards of five hundred years before the commencement of the Christian era. The still more surprising virtue, however, with which that mineral is endowed, of assuming a particular direction when it is freely supported on a pivot, does not appear to have been known to the ancients; for though Pliny[†] mentions several of its curious qualities with a sort of credulous enthusiasm, he does not once make the slightest allusion to its polarity. It is difficult to determine at what epoch this singular property was discovered, but it seems to have been partially known in Europe a considerable time before the invention of the mariner's compass,[‡] for in a work erroneously ascribed to Aristotle, but known to have existed in the 13th century, which is quoted by Vincent de Beuvais and Albertus Magnus, the polarity of the magnet is stated in terms so explicit as to leave no doubt that even at that early period it had been taken advantage of by mariners for the direction of their course. This opinion is still farther corroborated by a quotation adduced by Montucla from a French poet, of the name of Guyot de Provins, from which it appears that the polarity of the magnet had been known towards the close of the 12th century.[§] The opinion, however, which is most generally received on the subject is, that the mariner's compass was invented in the year 1302, by a native of Melphi, a town of considerable trade in the kingdom of Naples; though the name of the individual to whom mankind are indebted for an instrument which has contributed so essentially to the improvement of one of the most important arts of life, has not been transmitted by cotemporary historians. The defects of written testimony, with respect to the origin of this valuable discovery, are but ill supplied by the conjectures of later writers, whose researches have done nothing more than to render it probable that the mariner's compass was invented, or revived, by Flavio Gioia, an obscure individual, of whom nothing is known but the place of his nativity.

But, whoever was the real inventor of this admirable instrument, it is certain that, in little more than half a century after it was applied to nautical purposes in Europe, navigation assumed a bolder and more adventurous character. Human curiosity, which had been long repressed by scholastic dogmas, and superstitious prohibitions, began, about the same period, to shake off the fetters which had been imposed by false philosophy and mistaken views of religion, and to search, in the free exercise of the mental powers, for objects of more rational pursuit. The spirit of enterprise and discovery kept pace with the means which the progress of human knowledge gradually unfolded, to aid and direct its exertions; and the facility of mutual communication which navigation began to open up between remote countries was equally conducive to the benefit of individuals, and the general advantage of nations. From this era we may date the commencement of that kind of intercourse between the inhabitants of different countries, which properly deserves the appellation of commerce.

The Portuguese were among the first to signalize themselves in the career of geographical discovery which was now opened up by means of the mariner's compass. Under John I. a prince devoted to philosophical pursuits, and well skilled in the mathematical sciences, a small fleet was fitted out in 1412, to explore the western coast of Africa, and bring back whatever information could be obtained respecting the inhabitants and productions of these unknown regions. The expedition was sufficiently successful to keep alive the spirit of adventure by which it had been planned and conducted, and even to encourage the hope, that discoveries of still greater importance might be the result of a more extended system of maritime enterprise. Henry, Duke of Visco, the fourth son of King John, who, like his father, had been instructed in all the sciences of that age, and was particularly versant in geography, was accordingly entrusted with the sole management of these new and daring undertakings; and certainly no individual could have been selected, who was better qualified to superintend their execution. Guided by his directions, the Portuguese ranged along the coast of Africa till they approached within a few degrees of the equator, and discovered, at a little distance from the shores of that vast continent, the island of Madeira, the Cape Verd Isles, the Azores, and several other islands of inferior note.

It is unnecessary, in this sketch of the history of mathematical navigation, to give a detailed view of the various discoveries which were made under the direction of this enlightened prince; it is more immediately connected with our subject to state, that he seems to have been the first who suggested to the mariner the use of plane charts to delineate his course and distance from one place to another. His endeavours to improve the state of nautical science were ably seconded by Joseph and Roderic, two mathematicians of some eminence at that period, who were employed as physicians at the court of Lisbon. With their assistance, and that of Martin de Bohemia, a Portuguese by birth, who had studied under the celebrated Regiomantanus, he caused tables to be constructed of the sun's declination, and furnished navigators with instruments for deducing their geographical position by celestial observation.

The mariner's compass had not been long employed as a guide at sea, before it was discovered that the magnetic needle did not coincide exactly with the direction of the true meridian, and that its deviation from that line was even different at different places. This deviation, which is commonly called the *variation* of the compass, seems to have been first observed by the celebrated Columbus, on the 14th of September 1492, during his first voyage to America, though the discovery is also ascrib to Sebastian Cabot, a distinguished cotemporary navigator. Subsequent observations, made with better instruments, and under more favourable circumstances, have not only established this important fact, but demonstrated that the quantity of the variation is subject to regular periodical changes, the north indicated by the magnet being sometimes to the eastward, and sometimes to the westward of the true north. It has even been ascertained that a local variation, of sufficient magnitude to lead to considerable errors in a ship's reckoning, may frequently be occasioned by the attractive influence of the ferruginous particles diffused through the mass of materials of which the hull is composed; though the subject has not yet been investigated with sufficient attention to explain the anomalous appearances to which this source of variation is supposed to give rise. See Bain *On the Variation.*

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[*] Bossut, Hist. de Math. i. 252.

[†] Hist. Nat. Lib. xxxvi. c. 16.

[‡] Montucla Hist. de Math. i. 525.

[§] See *Edinburgh Philosophical Journal*, vol. iii. p. 124. Note.

The art of navigation, notwithstanding the great advantages which it had derived from the mariner's compass, was still in a very imperfect state. The use of the plane chart, first introduced by Prince Henry of Portugal, contributed, without doubt, to abridge the labour of the mariner in his attempts to delineate a representation of the ship's tract and position, but the errors which it introduced into his reckoning, especially in high latitudes, more than counterbalanced the simplicity of the principles on which it proceeded. The methods too, which are recommended, and attempted to be reduced to practice, for determining the ship's place by celestial observation, though founded on just views, were rendered in a great measure useless, by the rude and inadequate nature of the instruments which were employed to obtain the necessary data; while the astronomical tables, which were requisite in the calculation of the ultimate result, had not yet been drawn up with sufficient accuracy for that purpose. Thus, though it was suggested by Werner, so early as in the middle of the 16th century, that the longitude might be ascertained by observations of the moon, the lunar tables were much too limited and imperfect to enable the mariner to derive any benefit from the proposal; and watches, which had been recommended by Gemma Frisius about the same time, and for the same purpose, having been but recently invented, could not be used with any advantage for the solution of a problem, in which a high degree of accuracy is essential, for obtaining even an approximation to the truth.

The errors arising from the use of the plane chart, according to the principles on which it had hitherto been constructed, (which in fact were none other than the exploded opinion that the surface of the earth was an extended plane) were too obvious long to escape the notice of intelligent navigators; and we accordingly find, that about the beginning of the 16th century, some unskilful attempts were made to correct the ship's place on the chart, by means of a kind of equation table, which showed, upon an alteration of one degree of latitude, what distance had been run on each rhumb, together with the corresponding departure from the meridian. In the year 1537, the illustrious Nunez, or Nonius, a Portuguese mathematician, to whom the world is indebted for a very ingenious method of obtaining the subdivisions of an arch, without actually dividing it, published a dissertation, *De Arte et ratione Navigandi*, in which he pointed out, very distinctly and accurately, the cause of these errors, and explained, among a variety of other useful problems, a method of finding the latitude by two altitudes of the sun, and the azimuthal angle contained by the corresponding zenith distances He also remarked, that the oblique rhumbs, cutting the meridians at the same angle, are in reality spiral lines, which by each revolution round the globe, approach nearer and nearer to the pole; and that the course to be observed, in sailing from one place to another, so as to reach it by the shortest distance, ought to be the arch of a great circle of the terrestrial sphere. These views were afterwards taken up by Dr. Halley, who deduced from them a simple and ingenious method of calculating the enlarged portions of the meridian, adapted to each latitude, and known at present by the appellation of *meridional parts.*

Of the *Log*, that useful and necessary appendage to the mariner's compass, we find no mention in any of the treatises on navigation published before 1577, when it was described, probably for the first time, by Mr. William Bourne, in a work entitled, a *Regiment for the Sea.* The inventor of this simple contrivance for determining the rate of a ship's sailing is unknown; but the device itself is noticed by every subsequent writer on navigation. Other methods have been suggested for the same purpose, but they have generally proved either impracticable at sea, or too complicated to be brought into familiar use.

The period was now at hand, when the plane chart, the errors of which, on account of the sphericity of the earth, had become too manifest to admit of its being used any longer for nautical purposes, was about to receive a most important improvement, by which the meridians were still to be allowed to retain their parallelism, while the course and distance were to be laid down with equal simplicity as formerly, and the difference of longitude was to be indicated with a precision not hitherto obtained in any latitude. The means by which this desirable object was to be attained, were sought for by some augmentation of the distance of the parallels of latitude, from the equator to the poles, so as to compensate for the convergency of the meridians on the globe; but Gerard Mercator, a geographer of the Low Countries, by whom the method was first recommended, seems to have been unable to point out the precise law according to which it may be carried into effect. This was reserved for our countryman Edward Wright, who is generally allowed to have been the first person by whom the projection, which now bears the name of Mercator, was reduced to precise and accurate principles. He demonstrated that, if the meridian be supposed to be divided into small portions, the portions must suffer a gradual enlargement from the equator towards the poles, in a ratio corresponding, at each point, to the secant of the latitude. Wright explained the reason of this division, and its use in navigation, in a work which he published in 1599. In a second edition of his book, which came out in 1610, he added several improvements of considerable value, and recommended the measurement of a portion of the terrestrial meridian, as the best means of procuring an accurate basis for linear mensurations,—a standard of reference which has since been adopted in France, as the ground work of the national weights and measures. This edition of Wright's treatise contains a table of meridional parts, computed on the principles he had proposed for enlarging the meridian, and adapted to each minute of the quadrant,—a table of great value at that time, but which the ignorance and prejudices of the age prevented from being at first duly appreciated In the same work, the learned author describes an instrument which he called the *Sea-Rings*, by which the altitude of the sun, the hour of the day, and the meridian of the compass, might all be determined by inspection, in situations where the latitude was known. He also gave, what was then much wanted, a table of the declination of the sun for four consecutive years, and another of the places of a considerable number of the fixed stars, from observations of his own, made with a six-foot quadrant. His reputation as a mathematician having procured his appointment to the office of preceptor in geometry to Prince Henry of England, a youth of the most promising hopes, but who was prematurely cut off before he reached his eighteenth year, he contrived, for the instruction of his royal pupil, a large mechanical sphere, with which he exhibited all the celestial movements, and more especially those of the sun and moon, in so much that the eclipses of these luminaries could be predicted by means of it for a period of 17,100 years. A few years before his death, which took place in 1618 or 1620, his attention was directed to the calculation of logarithms, a species of numerical quantities first made known to the world by Lord Napier in 1614, and of the most extensive use in navigation and astronomy, as well as in some of the higher branches of the mathematics. See LOGARITHMS.

Wright's improvement on Mercator's chart soon became known abroad, where it seems to have been received with greater readiness, but less candour than in England. In 1624, Snellius, professor of mathematics at Leyden, published a treatise of navigation, on Wright's plan, which he entitled *Typhus Batavus*, but without making the slightest acknowledgment for the principles he had borrowed from it. Hence, several years after, we find some of the French writers, who generally show a very illiberal jealousy of English mathematicians, confidently asserting, that Snellius was the real inventor of the corrected charts. Montucla, however, has since admitted that this admirable improvement, though at first ascribed to Mercator, is entirely due to our countryman Edward Wright. Even ten years before the publication of the works of Snellius, every case in navigation had been solved numerically by Mr. Ralph Handson, in his nautical questions subjoined to a translation of Pitiscus's Trigonometry, by applying arithmetical calculations to Wright's table of meridional parts. Of the priority of Wright's claim, therefore, to the honour of this important invention, no person can any longer entertain the smallest doubt.

Another method of determining the change of longitude on an oblique course, and founded partly on the principles of plane sailing, and partly on those of parallel sailing, was at this time proposed by Mr. Handson, and found to answer extremely well in latitudes at no great distance from the equator. Two kinds of approximation were suggested, both of which were altogether independent of Wright's enlargement of the meridian: the first was obtained by taking an arithmetical mean between the cosines of the extreme latitudes, and the second by the same mean between their secants, and thus declining the difference of longitude from the departure, as given by plane sailing. A similar method, but neither so correct, nor yet more simple in its application, is still frequently employed by seamen, to whom it is known by the appellation of *middle-latitude sailing*. According to this method of computing the difference of longitude, which seems to have been first described by Gunter, in an edition of his works printed in 1623, the cosine of the mean of the two latitudes is employed instead of the mean of their cosines, as recommended by Handson.

The inventor of the logarithms, as we have already hinted, contributed greatly to facilitate the necessary calculations for determining a ship's place by the methods hitherto employed for that purpose. A table of the common form of logarithms adapted to the natural numbers, as we have described in the history of that excellent invention, was computed by Briggs, and first given to the world in 1618. This table served as the basis of the logarithms of the natural sines and tangents, and was so applied by Gunter, who drew up from it a table of the logarithms of these trigonometrical quantities for every minute of the quadrant, which he published in 1620. To Gunter the seaman is also indebted for the very useful scale which still bears his name, on which he inscribed the logarithmic lines for numbers, as well as for the sines and tangents of arches, and by help of which, and a pair of compasses, every question in trigonometry may be solved with the utmost expedition, and very considerable accuracy.

Having now reached a period in the history of navigation when the art, so far as the determination of a ship's place depends on her reckoning, was nearly as perfect as it is at the present day, before we proceed to describe the improvements which it afterwards received from astronomy by means of instruments of a proper construction to be used at sea, we shall briefly allude to a method of calculating the meridional parts, which is not only more refined in principle, but, in extreme cases, more correct in its application, than the mode employed by Wright. His method of enlarging the meridian, as we have already stated, consisted in the continued additions of the successive secants of portions of that great circle, increasing in an arithmetical progression, from the equator to the pole, the secants of tho increasing arches being in each latitude proportional to the rate of convergency of the meridians; but we have now to remark, that the resulting sums of these secants, or meridional parts as they are called, will only be perfect when the portions of the meridian for which they are calculated increase by infinitely small differences; because, strictly speaking, the degree of convergency is not the same throughout the whole of any arch, however small, and consequently when the arches increase by finite differences, errors must gradually accumulate in the results of a calculation founded on that supposition. This defect in Wright's method of enlarging the successive portions of the meridian was noticed very early, and was obviated to a certain extent, by diminishing the common difference between the arches to a single minute of the quadrant; but it was not removed entirely, till Henry Bond announced, in an edition of Norwood's Navigation, which he published in 1650, that the sums of the natural secants, or the enlargements of the meridian on the principles of Wright's projection, follow the same law as the logarithmic tangents of half the complements of the latitudes. The demonstration of this curious property was not given by Bond, who seems to have stumbled on the discovery by accident; but this defect was afterwards supplied by James Gregory, in his *Exercitationes Geometricæ*, printed at London in 1658. Another demonstration of it was also given by Barrow, in his *Lectiones Geometricæ*, when he proves that if r denotes the radius, and λ the latitude of a place, the sum of the secants in question is analogous to the logarithm of $\frac{r+\lambda}{r-\lambda}$, which is the same relation as that already noticed.—Lastly, Dr. Halley furnished a very beautiful demonstration of this important proposition, deduced from the properties of the logarithmic spiral, and the principles of the stereographic projection of the sphere on the plane of the equator.

In what follows of the history of navigation we shall briefly trace the progress of the art, so far as its improvement is to be ascribed to the advantages it has derived from the modern discoveries in astronomy, and the invention of instruments of a suitable construction for making observations on the heavenly bodies at sea.

The methods by which a ship's place is determined on the surface of the ocean, may be divided into *geografhical* and *astronomical*. The former, consisting in an application of the principles employed for calculating the ship's position by means of the course and distance only; and the latter, comprehending the various problems of the sphere by which the latitude and longitude of a place may be ascertained from celestial observations. These two general methods of finding a ship's place, though depending on very different data, must still be considered as having a certain mutual relation, without which the results of the one could not be connected with the deductions of the others. Thus the magnitude of the earth must be known by the measurement of lines on its surface, before celestial observations can, in many cases, be rendered subservient to geographical purposes; and, on the other hand, these very measurements cannot be conducted with a due attention to accuracy, without the aid of astronomical science. In like manner, the mariner's compass, from the variations to which the needle is liable, ceases to be on all occasions a faithful index of the ship's course, unless its bearings be rectified from time to time, by observations of the heavenly bodies, the only sure guides to which the mariner must ultimately appeal in all his difficulties; and even the log-line, the simplest of all nautical instruments, cannot be constructed of a proper length until the exact magnitude of the earth is determined.

The actual magnitude of the earth remained unknown long after its spherical form had been ascertained and admitted; and, indeed, it is only in modern times, when, by means of instruments of a refined and delicate construction, the most profound speculations of science have been brought to bear with practical effect on the objects to which they are directed, that the real figure and magnitude of the earth have been determined with certainty and precision. Without stopping, therefore, to examine the results of the more ancient measurements, the linear bases of which are too imperfectly known to enable us to reduce them with sufficient accuracy to modern measures of length, we shall briefly notice the more recent attempts which have been made, to ascertain these important points. Norwood's measurement, which was executed in 1635, and described very fully in a work published two years afterwards, entitled *The Seaman's Practice*, was immediately applied by the author to correct the gross errors which prevailed at that period in the divisions of the log-line; and though it gave the magnitude of the earth considerably beyond the truth, it was more correct than any measurement which had been attempted before that time. A degree, between London and York, corresponded by Norwood's measurement to 367,200 English feet. The measurement of a degree of the meridian was undertaken in France by Picard, in 1669, under more favourable circumstances: a base line of 5663 toises in length was carefully measured between Villejuive and Juvisy, and this line being connected by a series of triangles with the most remote point, the distance between the extreme stations was found by calculation to be 68.430½ toises, while the difference of latitude was discovered, by help of a six feet sector, to be 1° 11′ 57″. It was inferred from this measurement, that a degree of the meridian, the middle point of which was in latitude 49° 7′, was 57,064½ toises, or 364,900 English feet. After Newton demonstrated that the influence of attraction, combined with the centrifugal force arising from the earth's rotatory motion, must render the terrestrial sphere somewhat flattened at the poles, and protuberant at the equator, an additional motive was presented for prosecuting these measurements with greater accuracy. In different situations, measurements, on a very extensive scale, were accordingly set on foot by the most enlightened European governments, and conducted in various quarters of the globe, with an ardour and assiduity suited to the importance of the undertaking. By a comparison of the different results, it has been established that the earth is an oblate spheroid, of which the compression at the poles is $\frac{1}{312.13}$; the circumference of the elliptic meridian being 24855.84 miles, and that of the equator 24896.16 miles. Hence a geographical or nautical mile, deduced from the mean length of a meridional degree, is 6075.6 feet. See ASTRONOMY.

Astronomical observations being made at various places on the surface of the earth, it was altogether impossible to reduce them to any common point of reference, such as the centre of the terrestrial spheroid, without a knowledge of the true form and magnitude of the earth. The exact determination of the moon's place, an element of great importance in the calculation of the longitude, was, more especially, deeply involved in these measurements; and even the allowance to be made for elevation above the surface of the ocean, in observing the altitudes of celestial objects, could not be duly estimated, before the deflection of the terrestrial arch below its tangent had been correctly ascertained.

The earlier navigators seldom had recourse to astronomical observations for the correction of their reckoning, unless such as were of the simplest nature. The instruments they employed were too rude in their construction to be applied to any thing beyond finding the elevation of the polar star, or the meridian altitude of the sun; the only observations they required for a gross approximation to the ship's latitude. The *Astrolabe*, or *Astronomical Ring*, which was nothing but an arch graduated into degrees and half-degrees, and suspended at a particular part in the circumference, seems to have been one of the first instruments used, in the infancy of navigation, for taking the sun's altitude; and to this was afterwards added the *Cross-staff*, or *Arbalete*, which was considered better adapted for the measurement of celestial arches in general. The Astrolabe was recommended for taking observations at sea so early as 1485; the Arbalete was introduced at a later period, and is particularly described by John Werner, of Nuremburgh, as a fit instrument to find the distance of the moon from a fixed star, for the purpose of determining the longitude. The truth is, however, that both these instruments were exceedingly imperfect; neither of them possessing any thing in its construction which adapted it, in the slightest degree, to the peculiar circumstances in which observations are usually made at sea. About the year 1600, the Arbalete received a considerable improvement from the celebrated Davis, one of the most enterprising seamen of his day, who gave to the instrument under its new form the appellation of the *Back-staff*, on account of the position in which the observer stood with respect to the sun, at the time of making an observation. This instrument, which is commonly known by the name of *Davis's Quadrant*, was afterwards still farther improved by Flamstead and Halley, and continued to be almost the only instrument used for taking the altitudes of the celestial bodies at sea until the year 1731, when it was entirely superseded by Hadley's Quadrant, one of the most admirable inventions of the last century. By this happy contrivance, which seems to have been first suggested by Newton, celestial observations can be made at sea, nearly with the same facility as on land, the observer being but little incommoded by the agitation to which he is exposed from the motion of the vessel. The discovery of the principle on which Hadley's quadrant is constructed has been ascribed, by some writers, to Thomas Godfrey, of Philadelphia, who contrived a similar instrument about the year 1731; but, if Hadley is to be deprived of the honour of having invented the valuable instrument which bears his name, Godfrey's claims must yield to those of Newton, who proposed an instrument for measuring angles by two reflexions so early as 1699. Even before this period, the ingenious Dr. Hooke seems to have had an idea of an instrument for measuring angular distances by reflexion, as we find stated in the History of the Royal Society, by Sprat and Birch.

The introduction of Hadley's quadrant may be regarded as forming a most important era in the history of astronomical navigation; that valuable instrument being no less indispensably necessary in this department of the nautical art, than the mariner's compass is to the methods of determining a ship's place by her course and distance. At the time when this instrument came into general use, the tables of the sun and moon had been brought to a considerable degree of perfection by the joint labours of the most eminent astronomers in Europe; a circumstance which gave an additional value to the invention, by furnishing the mariner at the same time with data suited to the perfection of his instrument. The theory of universal gravitation had been confirmed by the most delicate observations; and nothing seemed wanting to render it applicable to the purposes of navigation, but a more complete developement of the effects of the simple law, which Newton demonstrated to be the grand ruling principle in the whole of the celestial motions. The labours of Flamstead and Halley contributed in no small degree to this end; but it is to the profound researches of D'Alembert and Clairaut, of Euler and Laplace, that the extreme accuracy of the present lunar tables is chiefly to be ascribed. Guided by the theory of Euler, the celebrated Tobias Mayer made a vast number of observations on the lunar motions, from which he drew up, with singular address, a set of tables that were found to correspond much better with the various irregularities of the moon's motion, than the deductions of the most distinguished analysts, who, following out a loftier and more independent mode of inquiry, had admitted nothing into their investigations except the simple law of universal attraction. Such, indeed, was the accuracy of these tables, that the British government, in 1763, ordered a recompense of 3000*l.* to be paid to the widow of Mayer, in consideration of the benefits which navigation had derived from the labours of her husband. Several important improvements were afterwards added to them by Dr. Maskelyne and Mr. Mason; and in their present form, as they were published by the Board of Longitude in 1770, they seldom give the moon's place 30″ from the truth, whereas the tables of Dr. Halley, which were in use before that period, sometimes gave an error of 7′ or 8′. From the year 1789 to the year 1804, they were employed, with the new equations of the British astronomers, in the calculation of the tables of the moon's place, as laid down in the Nautical Almanack; but subsequently the more correct tables of Burg, and, more lately still, those of Burckhardt, have been adopted in drawing up that useful work.

We shall close the history of navigation with a brief account of the methods which have been employed for determining the longitude at sea, by means of chronometers, or accurate time-keepers. The daily rotation of the earth on its axis being performed with the most perfect uniformity, it is evident that the sun must, in the course of twenty-four hours, be twice in the same plane with the meridian of every place, viz. at noon and midnight; and, consequently, that the angle formed by any two meridians, or the measure of their inclination, which in fact is their difference of longitude, may be estimated by the time which elapses between the sun being thus in succession in each of their planes. Could, therefore, an accurate time-keeper, duly regulated to the noon of some particular place, be transported, without any change in its rate, to the meridian of some other place, the difference between the noon given by the time-keeper, and the noon of the place indicated by the sun, would afford, after a proper allowance for the equation of time, a simple method of determining their difference of longitude. Accordingly, the British government offered, in 1714, a reward of 20,000*l.* to any individual who should construct a time-keeper, capable of being used at sea, and keeping time with sufficient accuracy to determine the longitude within 30 geographical miles; and, at the same time, to encourage artists of ingenuity to engage in the competition, smaller sums were promised, in cases where the approximation might deviate more widely from the truth. This proposal, so worthy of a generous and enlightened government, was somewhat modified by a new act of parliament, passed in 1774, by which a reward of 5000*l.* was offered for the invention of any time-keeper, or other method, capable of determining the longitude within 60 geographical miles, and double that sum, if it came within 30 miles of the truth. The commissioners of the board of longitude were at the same time impowered to grant 5000*l.* to the author of any lunar tables, which should not deviate more than 15″ in assigning the moon's actual place, and such smaller sums, at discretion, as might prove conducive to the main design of the act. In consequence of these encouragements, Mr. John Harrison, a most ingenious artist, who had long devoted his attention to the improvement of chronometers, and distinguished himself by several important inventions connected with horology, was induced to attempt the construction of a chronometer that might be entitled to the reward held out by the government of his country. Having finished his first time-keeper, its going was sufficiently correct to make him aim at higher improvements; and, after repeated attempts, prosecuted with the most unwearied perseverance, he at length produced a time-keeper, which satisfied so completely the conditions of the act of parliament, that, in 1765, the commissioners of longitude ordered the sum of 10,000*l.* to be paid to him, on condition of his making a full disclosure of the mechanism of his watch. The principles on which it was constructed were accordingly laid before the public, in a treatise which Harrison published in 1767, and which has frequently been cited as a proof that great inventive powers may belong to a mind which is nearly destitute of the faculty of arranging, in a plain and systematic form, the objects of his own conceptions. Notwithstanding the obscurity, however, in which Harrison's account of his time-keeper was written, it was sufficiently intelligible to enable artists to construct similar watches; and many chronometers have since been made, which have been found to answer the purpose equally well with that of the original inventor. It is only to be regretted, that the high price of those valuable mechanical contrivances has hitherto confined them, in a great measure, to the Navy, and the ships employed in the service of the East India Company.

Practice of Navigation.

The methods of determining the course and distance from one place to another, are attended with little difficulty; and if the mariner could always pursue, without interruption, his calculated course, the art of navigation would be comparatively easy. The outlines of the coast, however, and the variableness of the winds, frequently compel him to proceed towards his port by a circuitous and indirect route; and hence it becomes necessary, in the course of a long voyage, that he should have other means of ascertaining his position, from time to time, than such as are afforded by the various courses and distances on which the ship had previously sailed. In the following treatise, therefore, we shall consider the subject under two general aspects: 1st, The methods of determining a ship's place, by the application of geometrical principles to the data derived solely from her course and distance. And 2d, The methods of doing the same thing by the application of these principles to the data deduced from celestial observations. To the former of these divisions of the subject we shall give the name of *Geographical Navigation*; and, to the latter, that of *Nautical Astronomy*. It is scarcely necessary to observe, that neither of these branches of navigation can be thoroughly understood without a competent knowledge of practical mathematics, and the general principles of geography and astronomy. We must, therefore, presume that the reader is already acquainted with the nature of logarithms, the applications of trigonometry, and the doctrines of the sphere, in so far as the latter are connected with the relations of the various circles by which the positions of the heavenly bodies, as well as the situations of places on the surface of the earth, are determined. We must also take it for granted, that in both cases the mariner is furnished with an accurate table of the latitudes and longitudes of the most remarkable places, as well as with correct maps and charts of the coasts, bays, headlands, &c. which he may have occasion to visit. See Geography.

Part I. GEOGRAPHICAL NAVIGATION.

Geographical Navigation, used in the restricted sense we have attached to this department of the subject, is the art of conducting a ship from place to place, and of finding, when circumstances require it, her position without the assistance of astronomical observations. The only instruments we shall suppose to be employed for these purposes are such as are necessary for the direction of the ship's course, and the measurement of her distance, every thing else being supplied by trigonometrical calculation.

CHAP. I.

Of the Instruments necessary for directing a Ship's course, and determining her distance.

Section I. *Of the Mariner's Compass.*

The mariner's compass, the invention of which has contributed so much to the progress of navigation, is the only instrument used for directing a ship's course at sea. The most essential part of the instrument is a circular card of pasteboard, the circumference of which is divided into degrees, points, and quarter-points, the card being attached to a magnetic bar, crossing its centre, and supported at that point by a pivot on which it plays freely. The magnetic bar, commonly called the *needle*, is made of good steel of a moderate degree of temper, and magnetized artificially to a maximum state. The best form for the needle has been a matter of controversy; some recommending that it should be of a rectangular shape; others that it should be rhomboidal, or acuminated. The middle of the needle is usually furnished with a capsular bit of agate, the cavity of which, in an inverted position, is intended to rest on a sharp upright pin, called the *supporter*. If the supporter is made of steel, it ought to be highly tempered and well polished, in order to diminish as much as possible the friction of the agate, and thus allow the needle to assume readily its proper position; but perhaps it might be better, in all cases, to make the supporter of the hardest kind of bell-metal.

The supporter is fixed to the bottom of a brass or wooden hemispherical *box*, the mouth of which is covered with a plate of glass, to protect the card from agitation by the wind. The box containing the needle and its card thus supported, is retained in a horizontal position by means of two concentric rings, called jimbals, which are connected with each other by pivots, diametrically opposite, the outer ring being attached to a square box also by pivots, in such a manner, that the line which joins them is at right angles to the line joining the two former. The rings having an easy motion on the pivots by which they are supported, to whatever motion the external box is exposed, the hemispherical one remains with its surface always in a horizontal position.

The ship's course by the compass is indicated by the angle which her keel makes with the needle; and in oader that this angle may be duly estimated, the instrument is placed in a fixed position near the steersman, in a square compartment intended for its reception, called the *binnacle*, where it remains immoveable. The direction of the ship, in reference to the centre of the compass, is more distinctly pointed out by means of a vertical line drawn in the inside of the circular box. This line is called the *lubber's point*; and in steering a particular course, the corresponding point in the circular card must be kept by the management of the person at the helm to bear steadily upon it.

The circumference of the card, we have already stated, is divided into a certain number of equal parts, called points. The divisions coinciding with the direction of the needle, or the magnetic meridian, are marked *north* and *south*, at the corresponding sides of the card, while two other points, at the distance of a quadrant, are termed *east* and *west*. These four points constitute what are called the *cardinal points* of the compass. Each quadrant, comprehended between two cardinal points, is subdivided into eight points, which are named according to their local position, with respect to the cardinal points, and to one another. An explanation of the nomenclature which has been adopted, in the case of one quadrant, will apply, with a suitable change of terms, to the other three; and we shall therefore deem it sufficient to show in what manner the points of one of the quadrants, (the north east for example,) have received names. In the first place, then, the point of bisection between the north and east, from its mutual relation to both, is called North-East. In like manner, the bisection of the arch between north and north-east, is called *North* North-East, and that of the arch between east and north-east, by a like analogy, *East* North-East. The bisection of each of the four resulting arches divides the quadrant into eight points, each of which is named by writing, after the north, east, and north-east points, the term *by*, (used in the sense of proximity,) with one or other of the cardinal points annexed, according as the point to be named is contiguous to the one or the other. Thus, the point adjacent to N. E. towards the north, is called N. E. by N., while the one similarly placed towards the E. is termed N. E. by E. By a like mode of procedure, the point next to the north, towards the east, is called N. by E. and that next the east, towards the north, E. by N. The nomenclature of the other quadrants is precisely similar.

These points, named in the manner we have described, are reckoned, in point of numerical order, from the north towards the east and west, and also from the south towards the same points. The following table exhibits the number of each point, with the corresponding number of degrees, &c. measuring the angle which the rhumb of each point and quarter-point forms with the meridian.

Table of Points and Quarter Points of the Compass.

North-East Quadrant.	North-West Quadrant.	Points.	Deg.	Min.	South-East Quadrant.	South-West Quadrant.
		¼	2	49		
		½	5	37½		
		¾	8	26		
N. by E.	N. by W.	1	11	15	S. by E.	S. by W.
		1½	15	4		
		1¼	16	52½		
		1½	19	41		
N. N. E.	N. N. W.	2	22	30	S. S. E.	S. S. W.
		2¼	25	19		
		2½	28	7½		
		2¾	30	56		
N.E. by N	N.W. by N.	3	33	45	S. E. by S	S. W. by S.
		3¼	36	34		
		3½	39	22½		
		3¾	42	11		
N. E.	N. W.	4	45	0	S. E.	S. W.
		4¼	47	49		
		4½	50	37½		
		4¾	53	26		
N.E. by E.	N.W. by W.	5	56	15	S. E. by E.	S.W. by W.
		5¼	59	4		
		5½	61	52½		
		5¾	64	41		
E. N. E.	W. N. W.	6	67	30	E. S. E.	W. S. W.
		6¼	70	19		
		6½	73	7½		
		6¾	75	56		
E. by N.	W. by N.	7	78	45	E. by S.	W. by S
		7¼	81	34		
		7½	84	22½		
		7¾	87	11		
E.	W.	8	90	0	E.	W.

When the mariner's compass is fitted up with sights, which are upright pieces of brass fixed to the box, placed diametrically opposite to each other, and furnished with vanes for viewing a celestial object, in order to determine its magnetic bearing, the instrument thus modified is called an *Azimuth Compass*. The description of it will be given with more propriety under the head of Nautical Astronomy.

We have already stated, in the history of navigation, that soon after the discovery of the polarity of the magnet, it was ascertained that the needle of the compass neither pointed exactly north and south, nor stood in the same position with respect to the meridian in different places. From successive observations made afterwards, it was found that the variation was not a constant quantity, even in the same place; but that it was subject to a gradual change, according to a law which has not yet been determined with much precision. The celebrated Burckhardt has indeed given a formula to express the tangent of the variation, in functions of the time elapsed from 1663, which has been found to agree pretty well with observations made at Paris; but it is rather to be regarded as a dexterous adaptation of the arithmetic of sines to the phenomena in question, than as a general expression of the magnetic variation deduced from physical principles, and capable of universal application. The truth is, the variation is liable to temporary changes, which seem to be the effects of chemical rather than of physical agency. Thus the position of the needle is strongly affected by the aurora borealis, and even by a volcanic eruption occurring at a great distance from the place of observation. In this country, too, it has been observed, that the north pole of the needle gradually veers westward from about eight in the morning to two in the afternoon, after which it returns slowly to its former position. This diurnal variation, which extends to seven minutes in winter, and to double that quantity in summer, has been ascribed to the daily change of temperature, which takes place at the surface of the earth by the action of the solar rays; though it is more probably owing to the influence of some peculiar emanation from the sun, which has not yet been sufficiently examined. The fact, that a slender bar of steel may be magnetized by exposure to the violent rays of the prism, is strongly corroborative of this opinion.

In the year 1657, the compass had no variation at London, and it was observed to be in the same condition at Paris, in 1663. Since that period, a line traced on the surface of the earth, and passing through the different places where there was no variation, appears to have moved continually eastward with its northern extremity, while its southern parts have moved in an opposite direction. At the end of the 8th century, the line of *no variation* formed a kind of irregular curve, of double curvature, passing through the east side of Nova Zembla, and continuing its course through the middle of Asia, crossed the equator at the island of Borneo, in 120° of east longitude. It then proceeded in a south-east direction through the middle of New Holland, and crossing the southern frigid zone, appeared in the opposite hemisphere, a little to the eastward of the Brazils; after which, advancing northward, it crossed the equator at a point in 40° of west longitude. Veering gradually to the westward, it intersected the coast of America, near Washington, and after passing through Lake Huron, stretched onwards to a point a little to the westward of Coppermine river, beyond which it could no longer be traced. Maps having curves drawn on them to represent the kind and degree of the variation, in different places, are called *Variation Charts*.* See Geography, Plate CCLXIX. and Variation.

The magnetic variation, though attended with some difficulties to the mariner, is not without its advantages in navigation. The lines in the Variation Chart, denoting different degrees of variation, run for the most part in directions deviating but little from the meridian, and hence, when they are accurately laid down, they may frequently be employed for determining, within certain limits, the longitude. In the North Sea, for example, where the variable lines are nearly north and south, the variation decreases from Great Britain towards the east, at the rate of about a degree for every 30 nautical miles of difference of longitude, so that a degree of latitude corresponds in that latitude nearly to a degree of variation.

The different methods which are employed to ascertain the magnetic variation, will be explained and illustrated under Nautical Astronomy: at present, we shall take it for granted, that the variation, which undergoes but a slight change in a number of years, is known at each particular place, and shall therefore now proceed to point out the corrections which must be made on the courses, as indicated by the compass, in order to reduce them to the true bearings, in reference to the meridian. The variation is denominated *easterly* or *westerly*, according as the north pole of the needle points to the eastward or westward of the true meridian. In conformity with this manner of distinguishing the kind of the variation, it is evident, that when a ship is sailing directly north by the compass, in a part of the ocean where the variation is easterly, her true course will form with the meridian an angle inclining north-easterly, the measure of which will be the same as the variation. Thus, if the variation were two points easterly, her actual course would be N. N. E. and in general, when the variation is easterly, the true course is found by making an allowance on the course steered towards the right hand, equal to the quantity of the variation; and when it is westerly, in an opposite direction. In making the allowance, the person who does so must, in all cases, conceive himself to be at the centre of the compass. Thus, if a ship were sailing S. E. by E. by the compass, when the variation was $2\frac{1}{2}$ points easterly, the true course would evidently be $2\frac{1}{2}$ points nearer the south, or S. S. E. $\frac{1}{2}$ E.; whereas, had she sailed on the same course, when the variation was $2\frac{1}{2}$ points westerly, her true course would be E. $\frac{1}{2}$ S. or, as it might be otherwise expressed, E. by S. $\frac{1}{2}$ E.

On the other hand, if a ship's true or calculated course, from one port to another, is to be reduced to the course to be steered by the compass, the allowance for variation must, with respect to its two denominations, be reckoned in a way just the reverse of that which has been explained for the reduction of the magnetic to the true course. This is too obvious to require any illustration.

It frequently happens that the magnetic variation cannot be observed with sufficient accuracy at sea. to serve the purpose of correcting the deviation of the compass; and accordingly variation charts, and variation tables, have been published, from time to time, with the view of palliating an evil, which, on many occasions, may be attended with much inconvenience to the mariner. Dr. Halley drew up one of these charts in 1700, and Mountain and Dodson afterwards published another in 1750. The celebrated Buffon, who devoted a good deal of attention to the subject, also gave, in his *Natural History of Minerals*, which was published in 1788, an extensive set of tables, embracing the state of the variation in every country, where observations had at that time been made. Such tables, after a proper allowance is made for the annual change of variation, are of the utmost importance to the less experienced navigator.

In prosecuting observations at sea for determining the variation in different places, various navigators have noticed certain anomalies in the result, which they generally ascribed, either to imperfections in the instruments employed, or to unavoidable errors arising from the nature of the observations themselves. The existence of these irregularities was amply confirmed by the observations of Mr. Wales, who, in his Introduction to the Astronomical Observations which he made during his second voyage with Captain Cook, expressly states, that during the passage outwards from Great Britain to the Cape of Good Hope, differences of 5° in the variation were frequently observed, without his being able to account for them. He ascertained, however, that in the northern hemisphere the greatest westerly variation was obtained, when the ship's head was north and easterly; and the least when it was in an opposite direction. He also observed that there were considerable differences in the result, according to the position, on board of the ship in which the azimuth compass was placed, at the time of observation. The true cause of these discrepancies was first explained by Captain Flinders, who, after a great number of observations conducted in the most judicious manner, inferred that it was owing to the attraction of the iron in the ship. In confirmation of this opinion, he observed that in the northern hemisphere, when the ship's head was on the east side of the meridian, the north end of the needle was drawn to the *right* of its natural position, by which westerly variation was diminished, and easterly increased; while, on the other hand, when the ship's head was on the west side of the meridian, the north end of the needle was drawn towards the *left*, so that easterly variation was thus diminished, and westerly increased. In the southern hemisphere the circumstances were reversed, the south pole of the needle being there affected by the local attraction of the ship, in the same manner as its north pole was affected in the opposite hemisphere. In both hemispheres it was remarked, that when the ship's head was directed in the line of the magnetic meridian, no local effect was produced, the attraction of the ship then acting in the same direction with the magnetic poles of the earth. We shall resume this subject when we come to consider the methods of finding the azimuth of a celestial object.

Sect. II.—*Of the Instruments used at Sea to determine a Ship's Rate of Sailing.*

An accurate knowledge of the distance which a ship may have sailed in a particular direction, being no less essentially necessary for ascertaining her geographical position, than a knowledge of her course duly corrected for variation and other sources of error, various methods have been proposed at different periods, for measuring, with as much precision as possible, the distance run in some given interval of time. On account of the difficulty, however, of procuring a fixed object of reference on the surface of the ocean, the determination of this point, though of great importance to the seaman, has not been yet attended with all the accuracy that might be desired. Many of the methods which have been recommended for the purpose, are toó complicated to be practicable at sea; several of them are altogether nugatory; and not a few of them are founded on principles too questionable to be entitled to the smallest confidence.

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* See the *Edinburgh Philosophical Journal*, vol. iv. p. 115, 116, where the reader will find the latest Chart of Variation and Dip, constructed by M. Hansteen, and containing the recent observations of captain Ross, and captain Parry.

Of all the contrivances which have been proposed, the Log is still the most simple in principle, as well as the least liable to error in its application. This instrument consists of a flat piece of wood, in the form of the sector of a circle, generally about five or six inches radius, and a quarter of an inch thick, a quantity of lead being applied to the circumference of the arch sufficient to make the flat side assume a vertical position, when the whole is allowed to float in the water. A slender rope, called the *Log-line*, is attached at each extremity of the arch, by means of a sort of bridle, which is fixed at one end, but connected with the log at the other by a pin, capable of being detached by a sudden jerk, in order that it may allow the log to be more easily pulled home, after it has been used for determining the ship's rate of sailing. As it is of the utmost consequence that the log should retain a vertical position in the water, and preserve its plane steadily at right angles to the direction of the log-line, the bridle is sometimes connected with the log at three points, in the manner of the supporters of the scale of a balance, two of the ends of the diverging line being fixed, and the third detachable, for the same reason as in the other case.

The log-line, which is usually from 100 to 120 fathoms in length, being attached to the log in the manner described, is wound round a reel, from which it is permitted to uncoil itself after the log has been thrown overboard, so that the quantity of line run out being afterwards compared with the time, affords an easy method of determining the ship's rate of sailing. A certain portion of the line next the log is allowed to escape before the reckoning commences, in order that the log may be fairly out of the eddy of the ship's wake; this part of the log-line, which is called the *stray-line*, is generally made to extend about 10 or 15 fathoms from the log, and its termination is readily distinguished by an appropriate mark. The portion of time fixed upon, during which the log-line is allowed to run off the reel, is thirty seconds, and is commonly indicated by a half-minute glass. The log-line is accordingly divided, from the termination of the stray line, into as many equal parts as may be necessary, each of which has the same relation to a nautical mile, or 6076 feet, that half a minute has to an hour. By this mode of dividing the log-line, the number of these equal portions of it which the ship is observed to sail in half a minute, will evidently correspond to the number of nautical miles she is, at the time of the experiment, sailing per hour. But half a minute being the 120th part of an hour, the interval between two of these divisions ought to be the 120th part of 6076 feet, or 50 feet 7⅗ inches; it being safer, however, to have these intervals rather too short than too long, to guard against the danger of over-sailing the distance between one port and another, they are commonly made only 48 feet. This modification is the more necessary when it is considered, that the log, however well constructed, must always drive a little, and thus give the estimated rate of sailing less than the truth. To distinguish more readily the number of the divisions of the log-line, a piece of marline is inserted between the strands of the line, with as many *knots* on it as there are divisions reckoned from the stray-line; and hence, when a ship is sailing at the rate of a certain number of miles per hour, it is usual to say she is going so many knots.

In determining the distance by the log-line and half-minute glass, errors may arise, either from the log-line being inaccurate in length, or the half-minute glass not being duly adjusted; but it is easy to reduce the rate obtained, in such cases, to what it ought to be, if both had been correct. For let D be the correct distance, and d the apparent distance; also let $T = 30$ seconds, and $t =$ time in seconds given by the half-minute glass; lastly, let $L =$ length of a knot of a correct log-line, or 48 feet, and $l =$ length, in feet, of a knot of the given log-line. Then the computed distance run being directly as the time, and inversely as the length of the line in which it is estimated, we have

$$D : d = \frac{T}{L} : \frac{t}{l} :$$

$$\text{Hence } \frac{D \,.\, t}{l} = \frac{d \,.\, T}{L},$$

$$D \,.\, t \,.\, L = d \,.\, T \,.\, l :$$

$$\text{And } D = \frac{d \,.\, T \,.\, l}{t\, L} \quad \ldots\ldots \quad (1.)$$

If the log-line be correct, but the glass faulty, in which case, $L = l$,

$$D = \frac{d \,.\, T}{t} \quad \ldots\ldots\ldots \quad (2.)$$

And if the half-minute glass be correct, but the log-line faulty,

$$D = \frac{d\, l}{L} \quad \ldots\ldots\ldots \quad (4.)$$

The first of these expressions, which includes in it the other two, may be reduced to a more commodious form for practice, by substituting for T and L their respective values. We thus obtain

$$D = \frac{d \,.\, T \,.\, l}{t\, L} = \frac{30 \,.\, d \,.\, l}{48 \,.\, t} = \frac{5}{8} \times \frac{d \,.\, l}{l}.$$

In like manner (2.) becomes

$$D = \frac{30 \,.\, d}{t}.$$

And lastly, by a like substitution, (3.) becomes

$$D = \frac{d \,.\, l}{48}.$$

From these general expressions we deduce the following practical rules for correcting the distance, when either the log-line, or half minute glass, or both at the same time, are incorrect.

Case 1. *When the log-line is faulty, but the half-minute glass correct,*

Rule. Multiply together the length of a knot of the given log-line, and the estimated rate, and divide the product by 48. The quotient will be the true rate.

Example.—The hourly rate of sailing by a log-line, the interval between knot and knot of which is 42 feet, is 10 miles per hour, by a correct half-minute glass. What is the true rate?

$$\text{True rate} = \frac{10 \times 42}{48} = \frac{420}{48} = 8\tfrac{3}{4} \text{ miles per hour.}$$

Note. In ascertaining the interval between knot and knot of the given line, it will always be proper to measure the length of several, and then to take a mean of the whole.

Case II. *When the half-minute glass is correct, but the log-line faulty,*

Rule. Divide 30 times the estimated rate or distance by the number of seconds the glass runs, and the quotient will be the true rate or distance.

Example.—The hourly rate of sailing, according to a half-minute glass which runs out in 27 seconds, is 8 miles an hour, by a correct log-line. What is the true rate?

$$\text{True rate} = \frac{30 \times 8}{27} = 8\tfrac{8}{9} \text{ miles per hour.}$$

Note. The half-minute glass should be examined by a watch with a second hand, or by the swings of a pendulum vibrating seconds. Such a pendulum, of sufficient accuracy for the purpose, may be obtained by taking a small bullet, and suspending it from a peg by a slender thread; the distance between the peg and the centre of the bullet being rather less than 39⅛ inches. The oscillations of the pendulum, when it is put in motion, will not sensibly deviate from seconds, so that thirty swings may be reckoned equal to half a minute.

Case III. *When both the log-line and half-minute glass are faulty,*

Rule. Multiply 5 times the product of the estimated rate or distance into the length of a knot of the given log-line, and divide the result by 8 times the number of seconds the glass takes to run out. The quotient will be the true rate or distance.

Example I.—A ship's rate of sailing by a log-line, the interval between knot and knot of which is 45 feet, is 9 miles per hour, estimated by a glass which runs 35 seconds.—What is the true rate of sailing?

$$\text{True rate} = \frac{5 \times 9 \times 45}{8 \times 35} = \frac{2025}{280} = 7\tfrac{1}{4} \text{ miles per hour.}$$

Besides the sources of error connected with the length of the log-line, and the inaccuracy of the half-minute glass, there are others almost inseparable from this mode of estimating the distance, which cannot be so easily obviated. Of these, the most difficult to appreciate, and make allowance for, is the change of place to which the log is liable, after it is thrown overboard; for, in order that the quantity of line run off the reel may afford an accurate measure of the rate of sailing, it is evident that the log ought to retain, during the running of the sand-glass, the exact position in which it was at the instant the whole of the stray-line had made its escape. But the agitation of the surface of the sea, the influence of the winds, and the effect of currents, as well as the tension of the log-line itself, all conspire to give a motion to the log, and thus to produce a considerable degree of uncertainty with regard to the indications of the log-line. Different methods have been proposed to render the log stationary, or at least to counteract, as much as possible, the operation of the causes by which the stability of its position is affected, though none of them can be said to have fully answered the purpose.

One of the best contrivances to guard against the fluctuations to which the log is exposed at the surface of the water is that of Bouguer, an account of which was first published in the Memoirs of the French Academy for 1747. The log received the form of a *cone*, the diameter of whose base was 3 inches, and the slant height 6 inches. The log-line being passed through the axis of this cone, was fastened to it after 50 or 60 feet of the line had been drawn through, with the apex or point towards the reel. At the end of the line was attached a contrivance made of metal, called the *Diver*, which was made sufficiently heavy to allow the cone just to float with its apex at the surface. The diver was constructed of two square plates of tin, placed at right angles, and soldered together at the intersection of their diagonals. The size of the plates, to suit a cone of the above dimensions, is recommended by Bouguer to be 9¾ inches in the length of one of the sides. The diver is fixed to the line by a bridle, as in the case of the common log, one end of the bridle being fastened at one extremity of the diagonal formed by the intersection of the two plates, and the other by a pin at the opposite extremity of it, so as to admit of being detached when the log is to be pulled home. When this compound log is used, the diver will sink sufficiently deep to be beyond the influence of the superficial agitation, and thus the log itself will remain nearly in a fixed position, the cone being only affected by that part of the motion at the surface, which is the resistance of the cone to that of the diver. The relative resistance, in the case of a cone and diver of the dimensions adopted by Bouguer, is as 1 to 5, so that a log thus formed will drive only a fifth part of what a common log would do in like circumstances, and consequently the distance inferred by means of it will be, in many cases, nearer the truth.

When this log is employed, it is recommended to be thrown alternately with the common log. The difference between the rates given by the two, being augmented by its fourth part, is the correction to be applied to the rate obtained by the common log, at the middle time between the hours when they were respectively hove; and is additive or subtractive, according as the result given by the compound log is greater or less than that given by the common log.

The angle formed by the directions of the two logs being increased by its fourth part, will be an approximated correction to be applied to the apparent course, being allowed towards the right or left hand, according as the compound log, when a person looks from the ship towards it at the time it was hove, was to the right or left of the common log.

Many other instruments have been proposed for estimating a ship's rate of sailing, but all of them are liable to this insurmountable objection, that, being attached to some part or other of the ship, they give the distance as it is affected by every irregularity of her motion; whereas the log, with all its imperfections, exhibits the ship's motion in reference to a continuous line, of considerable length, on the surface of the ocean. And indeed it may safely be affirmed, that no mechanical contrivance, however accurately it is fitted to indicate the velocity of a ship in smooth water, can be employed for the purpose of measuring the distance she has sailed on the surface of the ocean, so long as it exhibits the *rectified* length of the line actually traced out by the ship, undulated as that line must be, both on account of the inattention of the steersman, and the agitated state of the water. The log, therefore, must be still regarded as not only the best contrivance which has yet been suggested for measuring a ship's rate of sailing, but as affording, in principle, the only sure method by which a knowledge of the distance sailed can be obtained.

CHAP. II.

Of the Instruments necessary for delineating a Representation of a Ship's Course and Distance, and solving other nautical problems.

The instruments necessary for this purpose are few in number, as well as simple in their application, including merely a pair of *compasses* and a ruler, with various lines traced on it, called *Gunter's Scale.*

Section I. *Of Compasses.*

This instrument is chiefly employed for describing circles and arcs, or for laying off or measuring straight lines. The form of the instrument is too well known to render a particular description of it necessary. Suffice it to say, that it consists of two diverging legs, moveable on a well-finished joint, the extremities of the legs, which ought to be of steel, being brought to fine points, in order that the instrument may be used for measuring with accuracy the most minute distances. In good compasses, the joint is so contrived as to admit of various degrees of *tightness*, so as to allow the instrument to play with facility, or be retained in some particular state of opening, when sameness of extension is required.

Though nothing but long practice can enable a person to manage this simple instrument in an easy manner, some general directions may not be altogether useless for guarding against an awkward and incorrect method of handling it. As it frequently happens that only one hand can be spared for adjusting and applying it, the learner should habitually accustom himself to use the instrument without having recourse to both hands, unless in very particular cases. In applying the compasses to a scale, or in measuring the length of a line, the instrument should be held nearly upright, no more pressure being applied to it than is sufficient to preserve the points from altering their position. In describing circles or arcs, the head of the compasses should be held between the thumb and middle finger, and then made to roll between the thumb and fore-finger, while one of the legs is allowed to rest gently on the paper, and the other is caused to touch it with an uniform pressure.

Section II. *Of Gunter's Scale.*

The various lines on this instrument, as we have stated in the history of navigation, were first laid down on a scale by Mr. Edmund Gunter. The ruler to which these lines are applied for the use of the mariner is commonly two feet in length, and about an inch and a half, or two inches, broad, both faces of it being graduated. The lines on the one face are employed for the construction and measurement of figures, both plane and spherical; and those on the other, for resolving, with the help of a pair of compasses, the different problems in navigation, and some of the more common operations of arithmetic. To distinguish the lines on the two faces from each other, we shall call the former *natural* lines, and the latter, *logarithmic*, or *artificial.*

The natural lines are the following:

	Marked.
Lines of equal parts -	
Chords - - -	CHO.
Rhumbs - - -	RHU.
Sines - - -	SIN.
Secants - - -	SEC.
Tangents - -	TAN.
Semi-tangents - -	S. T.
Longitude - - -	M. L.

1. *Lines of equal parts.*—The scales to which lines of equal parts are applied are of two kinds, and are denominated *simple* and *diagonal.*

The *Simple Scale*, (see Fig. 1. Pl. CCCIV.) is formed by drawing two parallel lines, and then dividing them at right angles into such a number of equal parts as the destined use of the scale may require. An additional division, AC, on the left hand, is retained, to be afterwards subdivided into 10 equal parts, for the convenience of obtaining intermediate lengths between the primary divisions. This scale can only be used for laying off a line, the dimension of which is expressed by two digits, unless 10 of the primary divisions be employed to represent an unit of the next highest order.

The *Diagonal Scale*, (Fig 2.) is constructed by drawing 11 equidistant parallel lines, and then dividing the upper line into as many equal parts as may be thought proper. Through each of the points of division lines are then drawn, cutting the parallel lines at right angles; and the first division, both above and below, is subdivided as before, into 10 equal parts. In this manner the primary and secondary divisions of the scale are obtained. The ternary or third order of divisions, which must be a tenth of the secondary, are procured by drawing diagonal lines from the 9th of the secondary divisions above, to the 10th of the same division below; from the 8th above to the 9th below, and so on in the case of each corresponding pair of the secondary divisions. By halving each of the primary divisions, and dividing the last one at the other extremity of the scales by diagonal lines, drawn in the same manner, another scale is obtained of half the dimensions. With either of these scales, a line, whose dimension is expressed by three digits, may be laid down or measured with the utmost precision. Thus, let it he required to take from one of these scales a line, whose length is expressed by 867; place one foot of the compasses in the intersection of the sixth secondary division, and the seventh ternary one, and then extend the other foot to the eighth primary division. The extent will correspond to 867. The same extent would also answer to 86.7, 8 67, .867, &c. or to 8670, 86,700, &c. according to the local value assigned to the leading digit; but whatever value is attached to the primary divisions in the measurement of any part of a figure, the same value must be supposed to belong to them in measuring all the other parts.

2. *Line of Chords.*—The line of chords, and the other circular lines on the same side of the scale, have a reference to one another, and are all adapted to the same radius, which is commonly two inches. Let CA. (Fig. 3,) represent that radius, and a circle being described with it about the centre C, draw the diameters AB and DE at right angles to each other. Divide one of the quadrants as DB into 9 equal parts, and having joined DB, transfer the chords of the several arcs reckoned

from D, to the straight line DB, and DB will be a line of chords, exhibiting every 10th division of the scale. The intermediate divisions are obtained by subdividing each of the principal divisions of the quadrant into 10 equal parts, and transferring their chords as before. The scale of chords is employed for laying down or measuring angles, the chord of 60°, which is equal to the radius, being always assumed as the radius of the measuring arc.

3. *Line of Rhumbs.*—The line of rhumbs, which is employed to lay down a ship's course when it is expressed in points, is described in the same manner as the scale of chords, only the quadrant is divided into 8 equal parts in place of 9. Each of the principal divisions is again subdivided into 4 equal parts, and the chords of the resulting arcs being transferred to the straight line AD, the scale of rhumbs is completed.

4. *Line of Sines.*—The scale of sines is constructed by dividing one of the quadrants, as BE, into 90 equal parts, as was done for the scale of chords. Perpendiculars to the radius CE from every division in the quadrant give the scale of sines reckoned from C towards E. This scale is chiefly used in the orthographic projection of the sphere.

5. *Line of Secants.*—Produce CE indefinitely to F, and through B draw BG parallel CF, and also of unlimited length. Through the centre C, and each division of the quadrant BE, draw straight lines intersecting BG in the divisions 10, 20, 30, &c. The distance of each of these divisions from C being transferred to the line CF, will form the line of secants, which comprehends in it the line of sines, the secant of 0 being equal to the radius, or sine of 90°.

6. *Line of Tangents.*—The construction by which the line of secants is obtained, gives at the same time the line of tangents, along the line BG. This line, and the line of secants, are chiefly employed in the stereographic projection of the sphere.

7. *Line of Semitangents.*—The semitangents of arcs are not, as the designation of these lines would imply, the halves of the tangents, but the tangents of half the corresponding arcs. Thus the semitangent of 40° is not half the tangent of the 40°, but the tangent of 20°. Hence the scale of semitangents may easily be obtained from the scale of tangents. It may also be obtained by joining the point A, and each of the divisions in the quadrant BD; the intersections of the lines thus drawn, with the line CD, will give along that line from C, the scale of semitangents. This line, as well as the two preceding, is used in the stereographic projection of the sphere.

8. *Line of Longitudes.*—To construct the line of longitudes, divide the radius AC into 60 equal parts, and through each of the divisions draw straight lines parallel to CE, and intersecting the quadrantal arc AE. The chords of the resulting arcs, reckoned from A, being transferred to the line AE, will give the line of longitudes. This line being applied, in an inverted order, to a corresponding line of chords, 60 in the line of longitude being against 0° on the line of chords, and 0 on the former line against 90° on the latter, if the divisions on the line of chords be considered a line of latitude, the opposite divisions on the line of longitude will exhibit the corresponding number of miles belonging to a degree of longitude, in each particular latitude. This compound line is used to show the convergency of the terrestrial meridians, and to perform instrumentally questions in parallel sailing.

The lines on the other side of the scale, which we have denominated Artificial or Logarithmic, are the following:

	Marked.
Sine Rhumbs, . . .	S. R.
Tangent Rhumbs, . .	T. R.
Numbers, ...	NUM.
Sines, ...	SIN.
Versed Sines, . . .	V. S.
Tangents, . . .	TAN.
Meridional Parts, . .	MER.
Equal Parts, . . .	E. P.

1. *The Line of Numbers.*—We begin with the construction of this logarithmic line, because all the other lines are constructed with reference to it. The purposes to which this line is usually applied, do not require that it should have numbers represented on it, such that the greatest should exceed the least more than 100 times; and accordingly, as the common logarithm of 100 is 2, and that of 10 is 1, the line of numbers is made to consist of two equal parts, the subordinate divisions in one of which have a reference to an order of units, ten times greater than those of the other. Let an accurate scale of equal parts, therefore, be constructed, of half the length of the proposed line of numbers, and for the sake of greater precision, let it be a diagonal scale, with ten primary divisions. Then, by the common logarithms, the logarithm of 10 being 1, and that of 1, nothing.

the logarithm of 2 = .30103
. . . . 3 = .47712
. . . . 4 = .60206
&c. &c.

So that if, to suit our diagonal scale, the logarithm of 10 be increased a thousand times,

the logarithm of 2 will become 301
. . . . 3 477
. . . . 4 602
. . . . 5 699
. . . . 6 778
. . . . 7 845
. . . . 8 903
. . . . 9 954

In like manner, the distance of the intermediate divisions, on the first half of the scale, reckoned from the beginning of it, will be obtained by taking the three first figures of the logarithms of 1.1, 1.2, 1.3, &c. which will be found to be 41, 79, 114, &c. These numbers, therefore, being taken from the diagonal scale, and applied successively from the beginning of the logarithmic scale, will give the points on the latter, corresponding to 1.1, 1.2, 1.3, &c. All the other intermediate divisions are obtained in the same way; and the construction of the other half of the scale is in no respect different from the first. It is scarcely necessary to observe, that if the first unit, at the beginning of the scale, be reckoned 1, the second unit is 10, and the third 100; whereas, if the first unit be accounted 10, the second is 100, and the third 1000; and so on with regard to any other value that may be attached to the first unit.

2. *The Line of Sine Rhumbs.*—From the same scale of equal parts which was employed in the construction of the line of numbers, take the distances expressed by

the three first figures of the arithmetical complement,* of the logarithmic sines of 7, 6, 5, points, &c. or the secants of 1, 2, 3, points, &c. rejecting the indices, and lay them off, towards the left hand successively, from the point corresponding to the sine of 90°, which is usually placed immediately below the last unit on the right hand of the line of numbers; and thus the scale of rhumbs will be obtained for the several points. The quarter points are laid down after the same manner.

3. *The Line of Sines.*—The construction of the scale of logarithmic sines differs in no respect from that of the rhumbs, only degrees are employed in place of points.

4. *The Line of Tangent Rhumbs.*—This scale, as far as 4 points, is constructed in the same manner as the scale of log. sines, by using the three first figures of arithmetical complements of the logarithmic tangents of 3, 2, and 1 points, or of the logarithms of the tangents of 5, 6, and 7 points, rejecting the index. The tangent of 4 points being equal to the radius, terminates the scale on the right hand. The points above 4, if the scale were extended from that point towards the right hand, would be at the same distance from 4, or the point corresponding to the radius, as the points as much below 4 are from that point. Hence, the points corresponding to 3 and 5 points, 2 and 6 points, and 1 and 7 points, are coincident on the scale, only the points above 4, though actually laid down to the left hand of the point corresponding to the radius, must be conceived, in the performance of problems, to extend to the right hand of it.

5. *The Line of Tangents.*—The scale of logarithmic tangents is constructed, like that of logarithmic tangent rhumbs, by employing the three first figures of the arithmetical complements of the log. tangents of 40°, 30°, &c. or of the logarithms of the tangents of 50°, 60°, rejecting their indices.

6. *The Line of Versed Sines.*—From the scale of equal parts, employed in the construction of all the preceding scales, take the distances expressed by the three first figures of the arithmetical complements of the logarithmic cosines of 5, 10, 15, &c. degrees, rejecting the indices, and lay off the double of these distances, respectively, from right to left of the extended scale. The divisions, thus obtained, will correspond to the log. versed sines of 10, 20, 30, &c. degrees.

7. *Meridional Line.*—Take the meridional parts for every 10° from Table II. and having divided them by 60, lay off, by means of some convenient scale of equal parts, the distance expressed by the several quotients. The line of equal parts, which is placed immediately above or below the meridional line, is divided into 19 principal divisions, marked from right to left, 0, 10, 20, &c. each of these divisions representing 10 degrees of the equator, or 600 nautical miles. The first division on the right from 0 to 10, is divided into 10 equal parts, each of which, therefore, corresponds to a degree of the equator, or 60 miles; and consequently, the bisection of each of these equal parts reduces the ultimate divisions to a distance representing 30 miles. The extent from the right hand extremity of the meridional line to any particular division being applied, in like manner, to the scale of equal parts, will indicate, in degrees, the meridional parts belonging to that division, reckoned from the equator. Also, the extent between any two divisions in the meridional line being applied to the line of equal parts will give, in degrees, the meridional difference of latitude between the two latitudes, expressed by the numbers at the extreme points of extent. Hence this compound scale may serve, instrumentally, the purposes of a table of meridional parts, the use and construction of which will afterwards be explained.

In using these logarithmic scales for the solution of arithmetical problems, in trigonometry or navigation, it follows, from the nature of logarithms, that the fourth term of four proportional magnitudes being to the third, as the second to the first, if these magnitudes be A, B, C, and D, we have

$$\frac{A}{B} = \frac{C}{D}$$

And logarithmically,

$$\text{Log. } A - \text{Log. } B = \text{Log. } C - \text{Log. } D.$$

That is, the extent from the log. A to the log. B, these two quantities being of the same kind, will reach from the log. C to the log. D, always carefully observing that the extent in the second case must be taken in the same direction as in the first. This circumstance, which must never be lost sight of, requires to be particularly observed in solving problems where the scale of logarithmic tangents is employed, and the third term is the tangent of 45° on the radius. In such cases, when the extent is from the left to the right, in respect of the two first terms, the extent ought to be taken in the same direction on the scale of tangents; but the manner of laying down the scale not admitting this, the extent is taken from right to left, only the complement of the number of degrees and minutes corresponding to it is taken, in place of the numbers actually marked on the scale. A similar precaution is to be observed when either the first or second term of an analogy is greater than 45°, the extent in the second case being always reckoned in the same direction of what it would have been, if the line of logarithmic tangents had been continued to the right hand of 45°.

CHAP. III.

Methods of Solving the various Cases in Geographical Navigation.

The earth being of a spherical form, (see Astronomy, and Geography,) the lines conceived to be traced on its surface, to represent the distance from one place to another, must, on the principles of spherical geometry, be great circles of the sphere; and the angles which these great circles make with each other, must also, in conformity with the assumed measure of a spherical angle, be the same as the angles formed by their respective planes. The solution of the various problems in navigation, either in reference to distance or angular position, would seem, therefore, at first sight, to require the application of spherical trigonometry, a branch of geometry not very accessible to the ordinary mariner, and which would have been attended with very great difficulties in reducing its deductions to the actual circumstances of the case. Happily, however, this is rendered wholly unnecessary, by means of a very simple, but ingenious contrivance, according to which the circles on the surface of the sphere are projected into straight lines; and the calculations connected with their magnitudes and positions brought within the range of plane trigonometry. For this reason, we shall first explain what is called plane sailing, in which it is assumed that the surface of the earth is an extended plane, as the results to which this supposition leads, though not true, may afterwards be modified by the contrivance we have alluded to, so as to accord with the actual figure of the earth.

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* The arithmetical complement of the sine, tangent, &c. of an arc, is the remainder obtained by subtracting it from 10.000000.

Sect. I.—*Plane Sailing.*

In plane sailing, the meridians are conceived to be all parallel to one another, as well as the parallels of latitude; and the ship's course is estimated by the angle which the line of direction, in which she has sailed, makes with the meridian. In delineating the ship's position with respect to the point from which she has set out, the straight line on which she has sailed is called the *distance;* the number of miles she has advanced northward or southward, is denominated the *difference of latitude;* and the term *departure* is applied to the perpendicular distance she has receded from the meridian. In exhibiting a geometrical representation of these lines, the meridians are drawn upwards and downwards, towards the top being reckoned northward, and towards the bottom southward. This being agreed upon, towards the right hand must be east, and towards the left west. The lines of rhumbs or chords, according as the course is expressed in points or degrees, are employed for laying down the angular position of the distance with the meridian; and the distance and difference of latitude, and departure, are all measured by some assumed scale of equal parts.

The difference of latitude and departure being always at right angles to each other, the lines by which they are represented will form with the distance a right-angled triangle. Hence any two of these being given, or the course, and any one of them, the other parts of the triangle will be determinable. The cases in plane sailing are therefore six in number.

Case I. *Given the course and distance, to find the difference of latitude and departure.*

Examples.—A ship from latitude 48° 50′ N. has sailed N. E. by E. ½ E. 436 miles.—Required the latitude come to, and the departure.

1. *By Construction.*—Draw the line AD, (Fig. 4. Plate CCCCIV.) of indefinite length, to represent the meridian, and at the point A, which denotes the place sailed from, make with AD, by means of the scale of rhumbs, an angle of 5½ points, in a direction upwards, and towards the right hand. From some convenient scale of equal parts, such as the larger diagonal scale, take off 436 with the compasses, and putting one foot on A, extend the other to C, and C will be the ship's place. Lastly, from C let fall a perpendicular on AD, and AB will be the difference of latitude, and BC the departure. These lines being successively applied to the same scale from which the distance was measured, will give the difference of latitude 206 miles, and the departure 385 miles.

2. *By Calculation.*

To find the diff. lat.

Radius, . . .	10.00000
Is to cos. course 5½, .	9.67339
As the distance 436, .	2.63949
	12.31288
To the diff. lat. 205.5, .	2.31288

To find the departure.

Radius, . . .	10.00000
Is to the sine course 5½ p.	9.94543
As the distance 436 miles,	2.63949
To the dep. 384.5 .	2.58492

Table I. entitled the Traverse Table, or the table of difference of latitude and departure, is constructed by this case, and is commonly computed for every degree of the quadrant in which the course may be expressed. We have not judged it necessary, however, in this work, to give a table for more than quarter points, that being sufficiently precise for ordinary purposes. Neither have we extended the distance beyond 240 miles, as it is easy, by taking some portion of the distance, to make that extent suit the solution of every case. The table of difference of latitude and departure being previously constructed, the difference of latitude and departure corresponding to any particular course and distance, may be found by inspection in the following manner.

3. *By Inspection.*—Search in Table I. for the course of 5½ points, which in the present example is found at the bottom of the table; and opposite half the distance 218, there is found in the difference of latitude column 102.3, and in the departure column 192.3. These numbers, therefore, being both doubled because the distance was halved, we obtain 204.6 miles for the difference of latitude, and 384.6 miles for the departure. The designation of the columns is taken at the top or bottom, according as the course is found at the top or bottom.

4. *By Gunter's Scale.*—The extent from the radius, or 8 points, to the complement of the course 2½ points on the scale of sine rhumbs, will be found to reach from 436 on the line of numbers, to 206; and the extent from 8 points to 5½ points on the scale of sine rhumbs, will be found, in like manner, to reach from 436 on the line of numbers to 384 on the same scale.

Lat. left	48° 50′ N.
Diff. Lat.	3 24½ N.
Lat. in	52° 14½′ N.

The ship having been in north latitude, and made 204½ miles, or 3° 24½′ of northing, the difference of latitude is added to the latitude left, to obtain the latitude come to.

Case II. *Given the course and difference of latitude, to find the distance and departure.*

Example.—A ship from latitude 25° 30′ N. has sailed S. S. E. ¾ E. until she has arrived in latitude 21° 14′ N. what distance has she sailed, and how many miles has she departed from the meridian left?

Lat. left = 25° 30′ N.
Lat. come to = 21 14 N.

4° 16′ = 256 miles.

1. *By Construction.*—Draw the meridian line AB, (Plate CCCCIV. Fig. 5.) equal to 256 by either diagonal scale; at the point A, representing the place sailed from, make with the meridian the angle BAC by the scale of rhumbs equal to the course 2¾ points; and from the point B draw the parallel of latitude BC at right angles to AB. The line AC, applied to the diagonal scale used in measuring AB, will give the distance 298 miles, and BC, applied in like manner, will give the departure 153 miles.

2. *By Calculation.*

To find the distance.

Radius,	10.00000
Is to sec. course 2¾ points,	10.06665
As diff. lat. AB 250,	2.40824
	12.47489
To distance AC 298.5,	2.47489

To find the departure.

Radius	10
Is to tan. course 2¾,	9,77770
As diff. lat. 256,	2.40824
	12.18594
To dep. 153.4,	2.18594

3. *By Inspection.*—Having found the course 2¾ points at the top of the table of difference of latitude and departure, search in the difference of latitude column for 128, the half of the actual difference of latitude; opposite to it the distance column will be found 149, and in departure column 76.6, each of which being doubled, we obtain 298 for the distance, and 153.2 for the departure.

4. *By Gunter's Scale.*—There being no logarithmic line of secants, the distance cannot be found in the scale by the analogy used in computing it arithmetically; but we have also cosine course to radius, as the difference of latitude to the distance, from which the distance may be found by the scale of sines thus: Extend from the complement of the course 5¼ points to 8 points on the scale of sine rhumbs, and that extent will reach from 256, the difference of latitude, to 298, the distance on the line of numbers. Again, from the radius or 45°, to 2¾ points on the scale of tangent rhumbs, will reach from 256 to 153, the departure on the line of numbers.

Case III. *Given the course and departure, to find the distance and difference of latitude.*

Example.—A ship from latitude 2°, 18′ N. has sailed S.W. ½ W. until she has made 185 miles of departure. What distance has she run, and in what latitude has she arrived?

1. *By Construction.*—Draw the meridian line AB, (Plate CCCCIV. Fig. 6.) and from A, the place sailed from, draw the line AD at right angles to AB, and equal to 185; through D draw DC parallel to AB, and intersecting the line AC, previously drawn so as to make with AB an angle equal to the course. Then AC will be the distance, and AB the departure, the former of which will be found to measure 239 miles, and the latter 152 miles.

2. *By Calculation.*

To find the distance.

Sine of course 4½ points,	9.88819
Is to radius,	10
As the departure 185	2.26717
	12.26717
To the distance 239.3,	2.37898

To find the difference of latitude.

Sine of course 4½ points,	9.88819
Is to cosine course,	9.80236
As the departure 185,	2 26717
	12.06953
To the diff. lat. 151.8,	2.18134

3. *By Inspection.*—Having found the course 4½ points at the bottom of the traverse table, opposite the departure 185, or rather 184.7, which is the nearest to it, occurs 239 in the distance column, and 151.6. or the difference of latitude column, the designation of the latter being taken at the bottom, because the course was found there.

4. *By Gunter's Scale.*—The extent from 4½ to 8, on the line of sine rhumbs, will reach from 185 to 239, on the line of numbers; also, the extent from 4½ to 3½ on the line of sine rhumbs will reach from 185 to 152 on the line of numbers.

Lat. left,	2° 18′ N.
Diff. lat.	2 32 S.
Lat. in	0° 14′ S.

The difference of latitude exceeding the latitude left, and being of a different denomination, the ship has crossed the equator, and arrived in south latitude.

Case IV. *Given the distance and difference of latitude, to find the course and departure.*

Example.—A ship from latitude 18° 12′ S. has run 218 miles between the N. and W. until she has arrived in latitude 15° 25′ S. What course did she steer, and what departure has she made?

Lat. left,	18° 12′ S.
Lat. come to,	15 25 S.
	2° 37 = 167 miles.

1. *By Construction.*—Having drawn the meridian line AB, (Plate CCCCIV, Fig. 7,) representing the difference of latitude 167 miles; from B draw BC at right angles to AB; then with an extent equal to 218, and one foot of the compasses on A, describe an arc intersecting the departure line on C. Join AC and BC, the departure will be found to measure 140 miles, while angle BAC, the course, will be found by the scale of chords to be 40°.

2. *By Calculation.*

To find the course.

The distance, 218,	2.33846
Is to the difference of lat. 167,	2.22272
As radius,	10.00000
	12.22272
To cosine course, 40°,	9.88426

To find the departure.

Radius,	10.00000
Is to the distance, 218,	2.33846
As the sine course, 40°,	9.80807
	12 14653
To the departure, 140° 2′	2.14653

Hence the course is S. 40° W., or S. W. by S. $\frac{1}{2}$ W. nearly.

3. *By Inspection.*—Search in the traverse table, computed to single degrees, until 218 is found in the column of distance, and 167 in that of difference of latitude; the departure will then be found in its proper column, while the course will be observed at the top or bottom of the table, according as the designations of the other quantities are at the top or bottom.

4. *By Gunter's Scale.*—From 218 to 167 on the line of numbers, will reach from radius, on the sine of 90°, to 50°, the complement of the course, on the scale of sines. Again, from 90° to 40°, on the scale of sines, will reach from 218 to 140, on the sine of numbers.

Case V. *Given the distance and the departure, to find the course and difference of latitude.*

Example.—A ship from lat. 30° 56′ N. has sailed 470 miles in a north-westerly direction, until she has made 325 miles of departure. What course did she steer, and in what latitude has she arrived?

1. *By Construction.*—Draw the meridian line AB, (Fig. 8) and through B. draw BC at right angles to it, and equal to the departure, 325; then from C, with an extent equal to the distance, 470, intersect the meridian in A. Join AC, and BC will be the departure, while the angle A B C will be the course, the former measuring 339 m.; and the latter 43$\frac{3}{4}$.

2. *By Calculation.*

To find the course.

The distance, 470, .	2.67210
Is to the departure, 325,	2.51188
As radius, ...	10.00000
	12.51188
To the sine course, 43° 45′	9.83978

To find the diff. lat.

Radius, ...	10.00000
Is to cos. course, 43° 45′	9 85876
As the distance, 470, .	2.67210
	12 53086
To the diff. lat. 339.5 m.	2.53086

Hence the course is N. 43° 45′ W. or N.W. by N. $\frac{3}{4}$ W. nearly.

3. *By Inspection.*—Search in the traverse table, until some part of the distance, as $\frac{1}{5}$ of it, (because in the present example the distance exceeds the limits of the table,) is found in the distance column opposite to $\frac{1}{5}$ of the departure in its column, which will be found to be when the course at the top is 44°, (or in the table we have given, which is only computed to quarter points,) when the course at the top is 3$\frac{3}{4}$ p. The corresponding difference of latitude is 66.5, which, being multiplied by 5, gives, by approximation, 333 for the difference of latitude. When the quantities are considerable, as in the above example, the method by inspection will often differ very widely from the truth. It is always possible, indeed, to make suitable corrections for the want of perfect accordance between the given quantities and those found in the tables; but to do this would be more tedious than the method by logarithmic calculation, which it is intended to simplify.

4. *By Gunter's Scale.*—From 470 to 325 on the line of numbers, will reach from 90 to 43°$\frac{3}{4}$, on the scale of sines; also, from 90 to 46°$\frac{1}{4}$, the complement of 43°$\frac{3}{4}$, on the scale of sines, will reach from 470 to 339 on the line of numbers.

Latitude left,	30° 56′ N.
Different latitude,	5 39′$\frac{1}{2}$ N.
Latitude come to,	36° 35′$\frac{1}{2}$ N.

Case VI. *Given the difference of latitude and departure, to find the course and distance.*

A ship from lat. 2° 18′ N. has sailed in a south-westerly direction, until she has arrived in lat. 3° 12′ S. and made 290 miles of departure. What was her course and distance?

Lat. left, .	= 2° 18′ N.
Lat. come to	= 3 12 S.
Diff. lat. .	= 5° 30′ = 330 miles.

1. *By Construction.*—Draw the meridian line AB equal to 330, the diff. of lat. and from B draw BC at right angles to AB, and equal to 290 the departure; the angle BAC (Fig. 10. Plate CCCCIV.) being measured by the scale of chords, will give the course, and AC applied to the scale of equal parts will give the distance.

2. *By Calculation.*

To find the Course.

The Diff. of lat. 330 .	2.51851
Is to the departure 290	2 46240
As radius . . .	10.00000
	12 46240
To the tan. course 41° 18′	9.04389

To find the Distance.

Sine of the course, 41° 18′	9.81954
Is to radius . . .	10.00000
As the departure 290 .	2.46240
	12.46240
To the dist. 439.4 . .	2.64286

By Inspection.—The difference of latitude and departure being both halved, are reduced to 165 and 145, and in this state we find them opposite each other nearly, in their respective columns, under 41° for the course, and opposite 219 for the distance. Hence 219 being doubled, (because the diff. of lat. and departure were each halved.) the distance is 438.

By Gunter's Scale.—From 330 to 290 on the line of Numbers, will reach from 45° to 41°$\frac{1}{3}$ on the scale of Tangents; and from 41$\frac{1}{3}$ to 90 on the scale of Sines will reach from 290 to 439 on the line of Numbers.

Section II.—*Of Parallel Sailing.*

Parallel Sailing is very limited in its application, being restricted to those cases in which a ship's course is either due east or west. As its principles, however, are derived from the supposition of the globular form of the earth, it is not only capable of being applied to the solutions of some interesting problems in geography, but, by a certain modification of the analogies to which it gives rise, it leads to a method of solving the several cases in plane sailing, which, though not strictly correct, seldom deviates so far from the truth, as to produce any serious error in a ship's reckoning.

The earth being of a spherical figure, the different meridians on its surface converge from the equator towards each pole, in the ratio of the radius to the cosine of the latitude; (See GEOGRAPHY;) and since the difference of longitude between two places is the arch of the equator intercepted between their respective meridians, their actual distance, when they are on the same parallel, is easily determined by that analogy.

The quantities concerned in parallel sailing being three in number, viz. the latitude, the difference of longitude, and the easting or westing in the given parallel, commonly called the departure, (any two of which are sufficient to determine the third,) it is evident, that in this species of sailing there may be three general cases. These we shall consider in order.

CASE I. *Given the latitude of a parallel, and the distance between two places on it, to find their difference of longitude.*

EXAMPLE.—What is the difference of longitude between two places which are 235 miles distant from each other, both being in the parallel of 43° 15′?

1. *By Construction.*—Method I. *By the scale of sines.* Draw the straight line PA (Fig. 10. Pl. CCCCIV.) equal to the sine of 90; and PC equal to the sine of the colatitude, that is, the sine of 46° 45′; then about P as a centre, with the distances PA and PC, describe the two arcs AB and CD; from C lay off, by a scale of equal parts, the chord CD equal to 235, and through P draw PD, producing it to B; lastly, join AB, and it will be equal to the difference of longitude.

Method II. *By the scale of Chords.* Construct a right-angled triangle ABC, (Fig. 11. Pl. CCCCIV.) so that BC may be equal to the distance 235, and angle ACB to the latitude; then will AC be equal to the difference of longitude.

2. *By Calculation.*

Cos. lat. 43° 15′ . .	9.86235
Is to the radius . .	10.00000
As the distance asunder, 235	2.37107
	12.37107
To the diff. long. 322.6	2.50872
Or, Radius	10.00000
Is to sec. lat. . .	10.13765
As the distance . .	2.37107
	12.50872
To the difference of long. 322.6	2.50872

3. *By Inspection.*—Search in the traverse table for a departure equal to the given distance, where the course in the table is equal to the complement of the latitude, and opposite to the departure, in the distance column, will be found the difference of longitude. The reason of this is obvious, from the manner of constructing the figure by the scale of chords.

4. *By Gunter's Scale.*—The extent from the complement of the latitude, viz. 46¾ to 90, on the scale of Sines, will reach from 235 the distance, to 323 the difference of longitude on the line of Numbers.

CASE II. *Given the difference of longitude between two places, lying on the same parallel, to find their distance.*

EXAMPLE.—A ship in latitude 48° 45′ N. Long. 20° 12′ W. has sailed directly east, until she has arrived in Long. 16° 40′ W. What distance has she run?

Long. left . .	20° 12′ W.
Long. come to .	16° 40′ W.
Diff. long. . .	3° 32′ = 392 miles.

1. *By Construction.—Using the scale of chords.*—Construct the right angle ABC, (Fig. 11. Pl. CCCCIV.) having angle ABC equal to 48° 45′ the latitude, and the hypothenuse AC equal to 392 the difference of longitude; then BC, being measured on the same scale, will give the distance or departure.

2. *By Calculation.*

Radius . . .	10.00000
Is to the Cos. Lat. 48° 45′	9.81911
As the diff. long. 392 .	2.59329
To the dist. or dep. 258.5	12.41240

3. *By Inspection.*—To the complement of the latitude as a course, and the difference of longitude as a distance, find a corresponding departure, and it will be the distance or departure required.

4 *By Gunter's Scale.*—From 90° to 41° 15′ the latitude, on the scale of Sines, will reach from 392 to 259 on the line of Numbers.

CASE III. *Given the distance between two places on the same parallel of latitude, and the difference of longitude, to find the latitude.*

EXAMPLE.—A ship from a place in longitude 2° 30′ W. after sailing 167 miles due east, is found by observation to be in longitude 2° 30′ E. In what parallel of latitude is she?

Long. left . . .	2° 30′ W.
Long. come to . .	2 30 E.
Diff. long. . . .	5 0 = 300 miles.

1. *By Construction.—Using the scale of Sines.*—Describe the arc AB, (Fig. 12. Plate CCCCIV.) with the sine of 90°, and, by a scale of equal parts, make the chord AB equal to the difference of longitude, 300 miles; join PA, and PB; and having made AC equal to the distance 167, through C draw CD parallel to PA, and PD being applied to the scale of sines, will give the complement of the latitude.

2. *By Calculation.*

The diff. of Long. 300 .	2.47712
Is to the dist. or dep. 167	2.22272
As radius, . . .	10.00000
	12.22272
To the cos. lat. 56° 10′	9.74560

3. *By Inspection.*—Search in the traverse table until 300, or some part of it, is found in the column of distance, opposite a like part of 167, in the column of departure; the degrees belonging to the course will be the complement of the latitude.

4. *By Gunter's Scale.*—From 300 to 167, on the line of numbers, will reach from 90° to 33° 50′, the complement of the latitude, on the scale of sines.

SECTION III. *Of Middle Latitude Sailing.*

The shortest distance between two points on the surface of a sphere is the intercepted arch of a great circle; but as every great circle, except the equator, cuts the different meridians at angles, which are continually and insensibly varying, the instrument which the seaman employs, for the direction of his course, cannot be used for sailing on an oblique great circle of the sphere, without incessant alterations of the ship's track, which it would not only be difficult to estimate, but exceedingly troublesome to reduce to practice. By sailing always on the same rhumb, that is, by causing the distance line to cut all the meridians at the same angle, the distance is increased a little beyond what is absolutely necessary, but the increase never becomes so considerable as to be productive of much inconvenience, and the facilities which are thus obtained for the regulation of the course more than compensate for all the advantages which would be derived from sailing on a great circle.

A ship's track, directed by the compass, is, therefore, not a great circle of the sphere, but a curve of a peculiar form, called the *Loxodromic*, which possesses the curious property of perpetually approaching the pole towards which it is inclined, always winding round it, but never reaching it in any finite number of revolutions. This curve, which is a curve of double curvature, has a good deal of analogy with the *logarithmic spiral*, as we shall point out more particularly in the introduction to Mercator sailing; at present it will be sufficient to consider the consequences which are deducible from the ship's course forming the same angle with each of the meridians which it intersects.

Let A and C, then, be two places on the surface of the globe; let P be the pole, and ÆQ the equator; also let DA and CB be the parallels of latitude passing through the two places, and PL and PÆ, their respective meridians; lastly, let AC be the distance, cutting all the interjacent meridians at the same angle. Then AL will be the latitude of A, and ÆC the latitude of C; also CB will be the distance of the meridians in the latitude of C, and DA their distance in the latitude of A. Lastly, the intercepted portion of the equator ÆL will be the difference of longitude between the two places. Let the distance AC be now conceived to be intersected by an infinite number of meridians, and through each point of intersection let parallels of latitude be drawn, we shall thus obtain an indefinite number of equiangular small triangles.

Hence $AC' : Aa = C'C'' : C'm = C''C''' : C''k = \&c.$

And the sum of all the infinitely small distances, of which AC is composed, will be to the sum of all the differences of latitude Aa, $C'm$, $C''k$, &c. as AB′ one of those distances to Aa the corresponding difference of latitude, that is, as the radius to the cosine of the course; and, consequently, the whole distance AC, will be to the whole difference of latitude AB, in the same ratio.

By proceeding in like manner, it is easy to prove that the distance is to the sum of all the departures, in the ratio of the radius to the sine of the course. These analogies, which are totally independent of the particular curvature of the terrestrial meridians, coincide exactly with the conclusions of plane sailing,—a circumstance which is evidently to be ascribed to the course being supposed in both cases to make always the same angle with the meridian. In the species of globular sailing, therefore, which we are about to consider, the difference of latitude and the departure will be derived from the course and distance, by means of the same analogies which were already employed in plane sailing; and the only quantity we shall have to determine upon other principles, will be the difference of longitude.

The total departure being made up of all the infinitely small meridional distances $C'a$, $C''m$, $C'''k$, &c. will evidently be greater than DA, but less than CB; but between these two parallels some intermediate parallel may be found, such that the meridional distances comprehended between the meridians passing through the two places, shall be exactly equal to the departure. A ready approximation presents itself to the determination of the parallel answering the condition required, by taking the arithmetical mean of the extreme latitudes. With this middle latitude and the departure, the difference of longitude is computed by the principles of parallel sailing.

The mean latitude thus found, though it will not correspond exactly with the latitude, which, from the nature of the case, should belong to the actual departure, (for it is always less than the truth,) yet for the most part the errors to which it leads are so inconsiderable, that it may be employed with the utmost safety in the solution of every nautical problem in which it could have been used, if it had been rigidly correct. Instead of the mean of the two latitudes, it has been recommended to take the arithmetical mean between their natural cosines, or, what is still nearer the truth, the arithmetical mean between their logarithmic cosines; but these methods being more troublesome, are seldom resorted to.

Though no additional analogies are necessary besides those we have already employed, for solving the different cases in Middle-latitude sailing, the following one obtained by combining two analogies, one of them in Plane, and the other in Parallel sailing, will frequently render the calculation of the unknown quantities more concise and direct:

By Plain sailing, Radius : Tan. course = Diff. lat. : Dep.
Parallel sailing, Cos. mid. lat : Rad. = Dep. : Diff. lon.
Hence, Cos. mid. lat. : Tan. course = Dif. lat. : Diff. lon.

The terms of this analogy may easily be arranged, so that any of them may become the last term. The various forms which it may thus be made to assume, together with the analogies in Plane sailing, will enable us to solve all the following cases. It is almost unnecessary to observe, that in finding the mean, or middle latitude, half the sum, or half the difference of the two latitudes, must be taken, according as they are of the same, or opposite denominations.

CASE I. *Given the latitudes and longitudes of two places, to find the course and distance from the one to the other.*

EXAMPLE.—What is the course and distance from the isle of May to the island of Heligoland?

Lat. isle of May .	56°	11′	22″	N.
——— Heligoland	54	11	34	N.
Diff. lat. . .	1	59	48	=119.8 m.
Sum of latitudes	110	22	56	
Half sum or mid. lat.	55	11	28	

Long. Isle of May	2 32 47 W.
——— Heligoland	7 53 13 E.
Diff long. . .	10 26 0=626 m.

1. *By Construction.*—Draw the indefinite line BC, (Plate CCCCIV. Fig. 14.) And having made the angle BCD equal to an angle measured by the degrees, &c. of the middle latitude 55° $11\frac{1}{2}'$, make CD equal to 626, the difference of longitude, by some convenient scale of equal parts. From D draw DA perpendicular to BC, and make AB equal to 119.8. Join AC, and it will be the distance, and angle BAC will be the course.

2. *By Calculation.*

To find the course.

Diff. lat. 119.8 . .	2.07846
Is to diff. long. 626 . .	2 79657
As cos. mid. lat. 55° 11′ 28″	9.75652
	12.55309
To tang. course 71° 28′	10.47463

To find the distance.

Cos. course 71° 28′ . .	9.50223
Is to radius . . .	10.00000
As the diff. lat. 119.8 . .	2.07846
	12.07846
To the dist. 376.9 . .	2.57623

Hence the course is S. 71° 28′ E. and the distance 376.9 miles.

3. *By inspection.*—To the complement of Mid.-latitude as a course, and the difference of longitude as a distance, find a departure; then with this departure and the difference of latitude find a course and distance.

4. *By Gunter's Scale.*—The extent from the difference lat. 120 to the difference long. 626, will reach from the complement of middle latitude $34^\circ\frac{4}{5}$ on the scale of sines towards the right, to a point which would be opposite the course on the scale of tangents; but the tangents not extending beyond 45°, the distance between that point and 90° in the sines must be applied to the scale of tangents from 45°, and it will be found to reach to 18° 30′; or rather, in the present case, to the complement of 18° 30′, viz. 71° 30′ the course. Again, the extent from the complement of the course 18° 30′ to 90° on the scale of sines, will reach from the difference of latitude 120, to the distance 377 on the line of numbers.

Case II. *Given one latitude, with the course and distance, to find the difference of latitude and the difference of longitude.*

Example.—A ship from a place in latitude 57° 15′ N. long. 1° 15′ W. has sailed N. E. by N. 295 miles. What is the latitude and longitude of the place she has arrived at?

By Construction.—With the given course and distance construct the right angled triangle ABC, as in plane sailing. (Plate CCCCIV. Fig. 15.) The difference of latitude AB being measured, will be found 245 m. and hence the latitude come to being 61° 20′, the middle latitude is 59° $17\frac{1}{2}'$. Make now the angle BCD $59^\circ\frac{1}{4}$, and having produced AB until it meets CD in C, CD will be the difference of longitude.

2. *By Calculation.*

To find the diff. lat.

Radius	10.00000
Is to the cos. course 3 p.	9.91985
As the dist. 295 . .	2.46982
	12 38967
To the diff. lat. 245.3 .	2.38967
Latitude left . .	57° 15′ 0″ N.
Difference of latitude .	4 5 18 N.
Latitude come to .	61 20 18
Sum of latitudes .	118 35 18
Middle latitude . .	59 17 39

To find the diff. long.

Cos. mid. lat. 59° 17′ 39″ .	9.70810
Is to tan. course 3 p. . .	9.82489
As the diff. lat. 245.3 .	2.38967
	12.21456
To diff. long. 321 . .	2 50646
Long. left . . .	1° 15′ W.
Diff. long. . . .	5 21 E.
Longitude in	4 6 E.

3. *By Inspection.*—To the course and distance the difference of latitude is found to be 245, and the departure 164. Next to the departure in its column, and the complement of middle latitude $30^\circ\frac{3}{4}$ or $2\frac{3}{4}$ p. the corresponding distance, being in the present case the difference of longitude, is 320 m.

4. *By Gunter's Scale.*—From 90° to 5 points on the scale of sine rhumbs will be found to reach from the distance 295, to the difference of latitude 245 on the line of numbers. Next from the complement of the middle latitude $30^\circ\frac{3}{4}$ on the scale of sines, to a point opposite 3 points on the scale of tangent rhumbs, will reach from the difference of latitude 245, to the difference of longitude 321 on the line of numbers.

Case III. *Given the bearing and latitudes of two places, to find their distance and difference of longitude.*

Example. A ship from latitude 43° 45′ N. longitude 48° 50′ W. has sailed S. S. E. $\frac{1}{2}$ E. and is now found to be in latitude 39° 15′ N. What distance has she been, and in what longitude is she arrived?

Lat. left .	43° 45′ N.
Lat. come to	39 15 N.
Diff. lat. .	4 30=270 m.
Sum of latitudes	83 0
Mid. lat.	41 30

1. *By Construction.*—With the course and difference of latitude, construct the right angled triangle ABC, (Plate CCCCIV. Fig. 16). Make the angle BCD equal 41° 30′, and having produced AB till it meets CD in D, the hypothenuse CD is the difference of longitude.

2. *By Calculation.*

To find the distance.

Cos. course 2½ p.	9.94543
Is to radius	10.00000
As the diff. of lat. 270	2.43136
	12.43136
To the distance 306.2 m.	2.48593

To find the difference of Longitude.

Cos. mid. lat. 41° 30′	9.87446
Is to tan. course 2½ p.	9.72796
As diff. of lat. 270	2.43136
	12.15932
To diff. of long. 192.7 m.	2.28486

Long. left	48°	50′	0″ W.
Diff. long.	3	12	42 E.
Long. in	45	37	18 W.

3. *By Inspection.*—With the course 2½ p. and the difference of latitude 270, find the distance and departure; then, with the departure in its proper column, and complement of middle latitude as a course, find in the distance column the difference of longitude.

4. *Gunter's Scale.*—The extent from the complement of the course 5½ points to 8 points on the scale of sine rhumbs, will reach from the difference of latitude 270 to the distance 306 on the line of numbers. Also the extent from 48° 30′, the complement of middle latitude, on the line of sines to a point opposite 2½ points on the scale of tangent rhumbs, will reach from the difference of latitude 270, to the difference of longitude 193 on the line of numbers.

Case IV. *Given the distance between two places, and their difference of latitude, to find the course and difference of longitude.*

Example. A ship from latitude 37° 56′ N. longitude 20° 15′ W. has sailed 428 miles on a north-westerly course, until she has arrived in Lat. 42° 25′. N. What course did she steer, and in what longitude is she arrived?

Lat. left	37°	56′ N.
Lat. come to	42	25 N.
	4	29=269 m.
Sum of latitudes	80	21
Middle lat.	40	10½

1. *By Construction.*—With the difference of latitude 269, and the distance 428, construct the right angle triangle ABC, (Plate CCCCIV. Fig. 17.) and angle BAC being measured will give the course; then make angle BCD 40° 10′, and having produced AB until it intersects CD in D, the hypothenuse CD will be the difference of longitude.

2. *By Calculation.*

To find the course.

The distance 428 m.	2.63144
Is to the diff. lat. 269 m.	2.42975
As radius	10.00000
	12 42975
Is to cos. course 51° 3′ 36″	9.79831

To find the difference of Longitude.

Cos. mid. lat. 40° 10½′	9.88314
Is to tang. course 51° 3′ 36″	10.09255
As diff. lat. 269 m.	2.42975
	12.52230
To diff. long. 435.7 m.	2.63916

Hence the course is N. 51° 3½′ W.

The difference of longitude may also be found by the following analogy, which, in the present case, is more convenient than the last, when it is applied to Gunter's scale.

Cos. mid. lat. 40° 10½′	9.88314
Is to sine of course 51° 3′ 36″	9.89087
As the dist. 428	2.63144
	12.52231
To the dif. long. 435.7	2.63917

3. *By Inspection.*—To the distance 428, and difference of latitude 269, find a course and departure; and then, with the departure in its proper column, and the complement of middle latitude as a course, find a distance, which will be the difference of longitude.

4. *By Gunter's Scale.*—From the distance 428, to the difference of latitude 269 on the line of numbers, will reach from 90° to 39°, the complement of the course, on the scale of sines; also from 49°⅚, the complement of middle latitude, to 51°, the course on the scale of sines, will reach from 428 the distance, to 436 the difference of longitude.

Long. left	20°	15′	0″ W.
Diff. long.	7	15	42 W.
Long. in	27	30	42 W.

A variety of other cases might be given in middle latitude sailing; but those which we have already considered are sufficient for every practical purpose; and, at any rate, the method of solution is so much the same in all of them, that it is quite unnecessary to dwell longer on so trite a subject.

Sect. IV.—*Mercator sailing.*

Though the principles on which middle latitude sailing is founded, so far as they depend on the figure of the earth, are free from every objection, yet the method of finding the difference of longitude by the mean of the two extreme latitudes, being only an approximation to the truth, the results to which it leads cannot be implicitly relied upon, either in very high latitudes, or indeed in any case when the distance is considerable, and the course on a rhumb, nearly intermediate between the cardinal points.

MERCATOR SAILING, so denominated from its supposed inventor, Gerard Mercator, also proceeds on the globular figure of the earth, with this important circumstance to recommend it in preference to middle latitude sailing, that the conclusions deducible from its first principles are not qualified by any subsequent assumption which is calculated to affect either their generality or their accuracy. Uniting all the advantages of globular sailing, with the simplicity, in regard to its practical details, of supposing the surface of the earth to be an extended plane, it conducts to a rigid solution of every problem in geographical navigation, without having recourse to any higher principles than such as have already been employed in plane sailing. Nor must it be overlooked, that by enabling the mariner to delineate the various quantities connected with the determination of a ship's track and position, by means of straight lines only, it affords a method of exhibiting those quantities far more simply and correctly than can be attained by any other projection of the sphere. This object, of so much consequence to Navigation, is happily accomplished by a very ingenious mode of transferring the lines on the surface of a sphere to a plane, without changing, in any degree, the relation of their magnitudes, and may be conceived to be effected mechanically in the following manner: Let the sphere be placed in a hollow circumscribing cylinder, the axis of which is of unlimited extent, and while the equator of the sphere is in contact with the internal surface of the cylinder, let both hemispheres be supposed to be gradually distended, so that the meridians may be enlarged, at every point, in the same proportion as the corresponding meridional distances, until the latter become equal, everywhere, to the distances of the meridians at the equator. When this takes place, it is evident that the meridians will all become parallel, and that the surface of the sphere will, at the same time, be brought in contact with the internal surface of the cylinder. It now only remains to conceive, that each point on the distended surface of the sphere is applied to the point with which it coincides on the cylindrical surface, and that the latter is afterwards unfolded until it becomes a rectangular plane. In this state it would exhibit a projection of the lines belonging to the sphere, on the principles of Mercator sailing. See GEOGRAPHY.

We have already stated, in the history of Navigation, that though charts constructed from these considerations bear the name of Mercator, the principles of the projections were first explained in a distinct and accurate manner by Edward Wright. The design of the projection being to combine the advantages of a plane chart, in which the meridians are all parallel straight lines, as far as that can be done in accommodation to the actual magnitude, and angular position of lines on the surface of the terrestrial sphere; Wright justly conceived, that the end in view might be attained by enlarging each portion of the meridian exactly on the same degree as the corresponding meridional distance was increased, to render the meridians parallel. But any meridional distance in a given latitude, being to the corresponding difference of longitude, or distance of the meridians at the equator, as the cosine of the latitude to radius, or as the radius of the secant to the latitude, it occurred to him, that if each successive portion of the meridian, from the equator to either pole, was enlarged in the proportion of the radius to the secant of the latitude, an adequate compensation would thus be made for the increase of the several parallels of latitude; and the different parts of the projection would everywhere retain the same relative magnitude which they possessed on the surface of the sphere. The only circumstance which, in the state of mathematical science at that period, might be considered as forming an insurmountable difficulty to a perfect solution of this apparently simple problem, was, that as each portion of the meridian, however indefinitely small, required a degree of enlargement peculiar to itself, the total increase could not be obtained without an infinite number of calculations. This difficulty, which is rather of a theoretical than a practical nature, was not entirely overcome by Wright, but it was at least so far obviated as not to affect materially the results of the calculations suggested by his method. He supposed a quadrant of the meridian to be subdivided into arcs, each a single minute, and having computed, on the principles we have described, the increase which each of the small portions of the terrestrial meridian ought to receive, according to its mean latitude, he afterwards added them together, in order to obtain for each respective latitude, the enlargement belonging to it, reckoned from the equator. The results of the calculation were then arranged in a table, each enlargement being placed opposite the corresponding latitude, and in this manner was obtained the first constructed table of *meridional parts.*

The calculation of a table of meridional parts, by this method, is greatly facilitated by means of a table of natural secants, the radius being unity; as the operation is then reduced to the addition of the natural secants of the successive arcs of 1′, 2′, 3′, &c.

$$\begin{array}{ll}\text{Thus merid. parts for } 1' = \text{sec. } 1' & \\ \rule{7em}{0.4pt}\ 2' = \text{sec. } 1' + \text{sec. } 2' & \\ \rule{7em}{0.4pt}\ 3' = \text{sec. } 1' + \text{sec. } 2' + \text{sec. } 3' & \\ \qquad\qquad\quad \&\text{c.} \qquad\qquad \&\text{c.} & \end{array}$$

This method of computing the meridional parts, answers perfectly well for all the ordinary purposes of Navigation; though it must be admitted, it would give rise to slight errors in very high latitudes. The enlargement due to each latitude has therefore been calculated on more rigid principles, by means of an analytical expression, according to which the meridional parts for one latitude are deduced, without being in the slightest degree dependent on the meridional parts for the preceding latitudes.

Before the invention of the fluxionary calculus, Henry Bond discovered, in 1650, that the sums of the secants follow the same relation as the logarithms of the tangents of half the complements of the latitudes; but he seems to have made this curious discovery in an empirical manner, as he never gave a demonstration of it. This was afterwards done, however, in various ways, by different mathematicians, particularly by Gregory, Wallis, and Halley. The demonstration of Halley, which was first published in the Philosophical Transactions for 1696, being one which may easily be understood by such as possess a knowledge of the first principles of logarithms, and the general properties of the stereographic projection of the sphere, is perhaps the simplest that has yet been proposed of Bond's proposition. We shall, therefore, give its leading steps, with some slight modifications to render the resulting expression more commodious for calculation.

We have already shewn, that the instrument which the mariner employs for the direction of his course is such, that it causes the distance line to cut all the meridians at the same angle. Let P, therefore, be the pole; AB a portion of the equator; *Acdeb* the ship's course, or the loxodromic line cutting the equidistant meridians, PA, PC, PD, &c. at the same angle, the whole being represented on the plane of the equator, according to the principles of the stereographic projection of the sphere. See Projection. By the nature of that projection, when the equator is the primitive, the meridians are projected into straight lines, and every angle on the surface of the sphere is also projected into an equal angle, on the plane of projection. Hence, all the triangles, PA*c*, P*cd*, P*de*, &c. are similar, and, therefore, P*a*, P*c*, P*d*, &c. are evidently in geometrical progression, while AC, AD, AE, &c. are in arithmetical progression.

Consequently, by the nature of logarithms, AC is the logarithm of P*c*, AD the logarithm of P*d*, &c.; but P*c* is, by the stereographic projection, the tangent of half the complement of C*c*, the latitude of *c*; P*d*, the tangent of half the complement of D*d*, the latitude of *d*, &c.; and AC, AD, &c. are the successive differences of longitude reckoned from A, by sailing from A to *b*. Hence, these differences of longitude become the logarithmic tangents of half the complements of the successive latitudes, when the course is on any oblique rhumb. The curve *Acdeb* representing the ship's course, is, in this projection, the same as the logarithmic spiral, so that a ship sailing on any oblique rhumb, would, if circumstances permitted, always approach the pole towards which her course inclined, without ever reaching it. Hence, we may draw this paradoxical conclusion, that unless a ship sail on some parallel of latitude, that is, unless she sail either due east, or due west, any other course intersecting the meridians would carry her always nearer and nearer one of the poles, around which her track would be a spiral; and yet, though she gradually advanced nearer the pole, she would never actually arrive at it, as this would imply that her direction could, at the same time, make the same angle with an infinite number of diverging lines.

The loxodromic curve, or rather the logarithmic spiral, into which it is projected stereographically, may give rise, according to the magnitude of the angle which it makes with the meridian, to an infinite variety of systems of logarithms. If the course be an angle of 45°, the resulting logarithms are of the kind denominated Neperean or Hyperbolic; but in that case the difference of longitude being exactly equal to the corresponding enlarged meridian, it follows, that the meridional parts belonging to that enlargement, must also be equal to the Neperean logarithms of the tangents of half the complements of the latitudes. So that if R denote the radius, which may be supposed unity; L the hyperbolic, and *l* the common logarithm of a number; and if λ be the latitude of a place, and M the corresponding meridional parts, in terms of the radius, we have

$$M = L \tan. \frac{90-\lambda}{2} \quad . \; . \; . \quad (1)$$

And, for any other latitude,

$$M' = L. \tan. \frac{90-\lambda'}{2}$$

Hence,

$$M' \mp M = L. \tan. \frac{90-\lambda'}{2} \mp L. \tan. \frac{90-\lambda}{2} \quad . \; . \; . \quad (2)$$

according as the latitudes are of the same, or opposite denominations.

And if $\lambda' = 0$, in which case the enlargement of the meridian will be reckoned from the equator.

$$M = L. \tan. 45° - L. \tan. (45° - \tfrac{1}{2}\lambda)$$
$$\text{or } M = L. R - L. \tan. (45 - \tfrac{1}{2}\lambda) \quad . \; . \quad (3)$$

$$\text{And } M = L. \left(\frac{R.}{\tan. (45 - \frac{1}{2}\lambda)}\right)$$

$$\text{But } \tan. (45 - \tfrac{1}{2}\lambda) = \frac{R - \tan. \frac{1}{2}\lambda}{R + \tan. \frac{1}{2}\lambda}$$

$$\text{Therefore, } M = L. \left(\frac{R\,(R + \tan. \frac{1}{2}\lambda)}{R - \tan. \frac{1}{2}\lambda}\right)$$

And if $R = 1$

$$M = L. \left(\frac{1 + \tan. \frac{1}{2}\lambda}{1 - \tan. \frac{1}{2}\lambda}\right) \quad . \; . \; . \; . \quad (4)$$

This expression is easily developed in the form of a series, and becomes, in the hyperbolic system, tan. $\frac{2}{1}\lambda$ being the natural tan. $\frac{1}{2}\lambda$,

$$M = 2 \left\{ \tan. \tfrac{1}{2}\lambda + \tfrac{1}{3}(\tan. \tfrac{1}{2}\lambda)^3 + \tfrac{1}{5}(\tan. \tfrac{1}{2}\lambda)^5 +, \text{ \&c.} \right\} \quad . \; . \; . \quad (5.)$$

If M is expressed in minutes, its value in these different expressions must be multiplied by the number of minutes contained in an arc equal to the radius; that is, it must be multiplied by 3437.75, &c. that being the number of minutes in the radius when the circumference is 360°×60, or 21600′. We shall thus obtain for (3) and (4)

$$M = 3437.75 \left\{ L. R - L. \tan. (45° - \tfrac{1}{2}\lambda) \right\} \quad . \; . \quad (6)$$

$$M = 3437.75 \; L. \left(\frac{1 + \tan. \frac{1}{2}\lambda}{1 + \tan. \frac{1}{2}\lambda}\right) \quad . \; . \; . \; . \; . \quad (7)$$

The two last expressions, which are very commodious for the calculation of the meridional parts, may be brought to a form adapted to the common logarithms, by dividing the co-efficient 3437.75, &c. by the modulus of the common system .43429448, &c. which reduces it to 7915.71, &c. We thus obtain,

$$M = 7915.71 \left\{ l. R - l. \tan. (45° - \tfrac{1}{2}\lambda \right\} \quad . \; . \quad (8)$$

$$\text{And } M = 7915.71 \; l. \left(\frac{1 + \tan. \frac{1}{2}\lambda}{1 - \tan. \frac{1}{2}\lambda}\right) \quad . \; . \; . \quad (9)$$

The expression (8) may be reduced to a form still more convenient for calculation, by substituting for tan. $(45 - \frac{1}{2}\lambda)$ its equal $\frac{R^2}{\cot. (45° - \frac{1}{2}\lambda)}$, by which we obtain,

$$M = 7915.71 \left\{ l. \cot. (45° - \tfrac{1}{2}\lambda) - l. R. \right\} \quad (10)$$

This expression, exhibited in common language, gives us the following rules for the calculation of the meridional parts:

I. *From the logarithmic cotangent of half the complement of the latitude, subtract the logarithm of the radius, and multiply the difference by* 7915.71.

II. Or, *Add 45° to half the latitude, and from the logarithmic tangent of the sum subtract the logarithm of the radius, and then multiply the difference, as before, by* 7915.71.

Examples.—What are the meridional parts for 57° 30′?

By Rule I.

Half complement of lat. $= \frac{90-57° \, 30'}{2} = \frac{32° \, 30'}{2} =$ 16° 15′.

Log. cot. 16° 15′, deducting the log. of rad. = 5354.
Hence, mer. parts of 57° 30′ = .5354 × 7915.71 = 4238.07.
What are the meridional parts for 85° 36′?

By Rule II.

Half the lat. $= \frac{85° \, 36'}{2} = 42° \, 48'$.

Log. tan. (42° 48′+45°)=Log. tan. 87° 48′=11.41549.

From which, subtracting 10, there remains, 1.41549.

And, 1.41549×7915.71 = 11204.6 = mer. parts for 85° 36′.

From the principles we have deduced above, the method of constructing charts by Mercator's projection, is easily derived; but as we have already explained very fully the nature of this projection, so far as the construction of maps is concerned, we must refer to Geography, for farther information on the subject.

To afford an opportunity of comparing the results obtained by Middle Latitude Sailing, with those deduced from Mercator Sailing, we shall employ, in solving the different cases, the same examples which we have already given under the former of these branches of geographical navigation. It is unnecessary to observe, that the difference of latitude and departure will preserve, in Mercator Sailing, the same relation to the course and distance which we showed they possessed in Middle latitude sailing, and that the former will be to the latter as the meridional difference of latitude to the difference of longitude.

Case I.—*Given the latitudes and longitudes of two places, to find the course and distance from the one to the other.*

Example.—What is the course and distance from the Isle of May to the Island of Heligoland?

Lat. Isle of May .	56°	11′	22″	
Lat. Isle of Heligoland	54	11	34	
Diff. of lat. . .	1	59	48	=119.8 m.

Merid. parts	56°	11′	22″ .	4094
———	54	11	34 .	3884
Mer. diff. lat. . . .				210

Long. Isle of May .	2°	32′	47″	W.
Long. Isle of Heligoland	7	53	13	E.
Diff. long. . .	10	26	0	=326

1. *By Construction.*—Draw the meridian line AD, (Fig. 19. Plate CCCCIV.) equal to the meridional difference of latitude 210, and AB equal to the actual, or proper difference of latitude 120; from D draw DE at right angles to AD, and make it equal to the difference of longitude 626: lastly, through B, draw BC parallel to DE, and AC will be the distance, and angle DAE the course.

2. *By Calculation.*

Mer. diff. lat.	210	.	2.32222
Is to diff. long.	626	.	2.79657
As rad.		.	10.
			12.79657
To tan. course	71° 27′		10.47435

Radius . . .		10.
Is to sec. course 71° 27′		10 49739
As diff. lat. 119.8 . .		2.07846
		12.57585
To the dist. 376.6 m.	.	2.57585

Hence, the course is S. 71° 27′ E. and distance 376.6 miles.

3. *By Inspection.*—To the meridional different latitude, in the different latitude column, and the difference of longitude in the dep. column, find a course; and then with that course, and the proper difference of latitude, find a distance.

4. *By Gunter's Scale.*—The extent from 210 to 626 on the line of numbers will reach from 45° to 18° 30″, or rather to the complement of 18° 30′, viz. 71° 30′ the course on the scale of tangents. The distance is found as in middle latitude sailing.

Case II.—*Given one latitude with the course and distance, to find the difference of latitude and difference of longitude.*

Example.—A ship from a place in latitude 57° 15′ N. longitude, 1° 15′ W. has sailed N. E. by N. 195 miles. What is the latitude and longitude of the place she has arrived at?

1. *By Construction.*—With the given course and distance, construct the right-angled triangle ABC, (Fig. 20. Plate CCCCIV.) as in plane sailing. The difference of latitude AB, being measured, will be found 245 m., and hence the ship having arrived in latitude 61° 20′, the meridional difference of latitude is, by the Table of meridional parts, 483. Make AD, therefore, 483, and having drawn DE parallel to BD, it will give, by measurement, the difference of longitude 321 miles.

2. *By Calculation.*—To find the difference of latitude.

Radius . .	.	10.00000
Is to cos. course 3 p.	.	9.91985
As the dist. 295 m.	.	2.46982
		12.38967
To the diff. lat. 245.3	.	2.38967

Lat. left	57° 15′ 0″ N.	Mer. parts	4210
Diff. lat.	4 5 18 N.		
Lat. come to	61 20 18 N.		4691
		Mer. diff. lat.	481

To find the difference of longitude.

Radius	10.00000
Is to the tan. course 3 p.	9.82489
As mer. diff. lat. 481.	2.68215
	12.50704
To diff. long. 321.4	2.50704
Long. left	1° 15′ 0″ W.
Diff. long.	5 21 24 E.
Long. in	4 6 24 E.

3. *By Inspection.*—To the course 3 points, and distance 295, find the difference of latitude 245. Then, having found the latitude come to, and consequently also the meridional difference of latitude; with the course, find the meridional difference of latitude in the difference of latitude column, and opposite to it, in the departure column, will be found the difference of longitude.

4. *By Gunter's Scale.*—From 8 points to 5 points, on the scale of sine rhumbs, will reach from the distance 295 to the difference of latitude 245, on the line of numbers. Also, from 8 points to three points, on the scale of tangent rhumbs, will reach from the meridional difference of latitude 481 to the difference of longitude 321, on the line of numbers.

Case III. *Given the bearing and latitude of two places, to find their distance and difference of longitude.*

Example. A ship from lat. 43° 45′ N. long. 48° 50′ W. has sailed SSE. ½ E. and is now found by observation to be in lat. 39° 15′ N. What distance has she run, and in what longitude is she arrived?

Latitude left	43° 45′ N.
Latitude come to	39 15 N.
Difference latitude	4 3 =270 m.
Meridional 43° 45′	2925
——— 39 15	2564
Meridional difference latitude	361

1. *By Construction.* Draw the meridian line AD, (Plate CCCCIV. Fig. 21.) and on it lay off AB and AD, equal to the proper and meridional differences of latitude, the former being 270, and the latter 361. Make the angle DAE equal to the course 2½ points, and from B and D, draw BC and DE, each at right angles to AD; then AC will be the distance, and DE the difference of longitude.

1. *By Calculation.*

To find the distance AC.

Radius	10.00000
Is to sec. course 2½ p.	10.05457
As diff. lat. 270	2.43136
	12.48593
To the dist. 306.2	2.48593

To find the difference of longitude.

Radius	10.
Is to tan. course 2½	9.72796
As mer. diff. lat. 361	2.55751
	12.28547
To diff. long. 193	2.28547
Long. left	48 50 W.
Diff. long.	3 13 E.
Long. in	45 37 W.

3. *By Inspection.*—With the course 2½ points, and the diff. of lat. 270, find the distance 306, and then, with the course and mer. diff. lat. in the diff. of lat. column, find, in the departure column, the difference of longitude.

4. *By Gunter's Scale.*—From the complement of the course 5½ points, to 8 points, on the scale of Sine rhumbs, will reach from the dif. lat. 270, the dist. 306 on the line of Numbers. Again, from 4 points to 2½ points, on the scale of Tangent rhumbs, will reach from the meridional difference of latitude 361, to the difference of longitude 193, on the line of Numbers.

Case IV. *Given the distance between two places, and their difference of latitude, to find the course and difference of longitude.*

Example.—A ship from latitude 37° 56′ North, longitude 20° 15′ West, has sailed 428 miles in a north-westerly direction, until she has arrived in latitude 42° 25′ North. What course did she steer, and what longitude is she come to?

Lat. left	37 56′ N.	Mer. parts	2463
Lat. come to	42 25 N.	Mer. parts	2815
Diff. lat.	4 29 = = 269 m.	Mer. diff. lat.	352

1. *By Construction.*—Draw the meridian line AD, (Fig. 22. Plate CCCCIV.) making it equal to 352, and from A lay off AB, equal to 269. From B and D, draw BC and DE, at right angles to AD, and of indefinite length. Then, from the point A, with an extent equal to 428, intersect BC in C; join AC, and prolong it to E. The angle BAC will be the course, and DE the difference of longitude.

2. *By Calculation.*

To find the Course.

Diff. of lat. 269,	2.42975
Is to Dist. 428,	2.63144
As Radius,	10.00000
	12.63144
To Sec. Course 51° 3′ 36″,	10.20169

To find the difference of Longitude.

Radius	10.00000
Is to tan. course, 51° 3′ 36″,	10.09255
As mer. diff. lat. 352,	3.54654
	12.63909
To diff. long. 435.6	2.63909

Long. left . . 20° 15′ 0″ W.
Diff. long. . . 7 15 36 W.

Long. come to, . 27 30 36 W.

3. *By Inspection.*—To the distance 428, and difference of latitude 269, find a course; then with the same course, and meridional difference of latitude 352, found on the diff. of latitude column, opposite to it, in the departure column, will be found the difference of longitude.

4. *By Gunter's Scale.*—From the distance 428, to the difference of lat. 269, will extend, on the scale of sines, from 90° to 39°, the complement of the course. Again, from 45° to 51°, or its complement 39°, on the scale of tangents, that is, in the present case, from left to right on the scale, will reach from the meridional difference of lat. 352 to the diff. long. 436.

Various other cases might be given, but being of no practical use, they are to be considered rather as trigonometrical exercises, than nautical problems.

SEC. V. *Traverse Sailing.*

WHEN a ship has sailed successively upon several courses, the distances belonging to which are of no considerable extent, it is usual, instead of computing the ship's place for each of them separately, to calculate the course and distance from the aggregate amount of the several differences of latitude and departures, found by inspection; and then to deduce, either by the principles of Middle latitude or Mercator sailing, the corresponding difference of longitude.

The irregular line described, in such cases, by the ship, is called a *Traverse;* and it is said to be *solved* when the several courses and distances of which it is compounded, are reduced to a single course and distance, which would have led to the same point.

The determination of the resulting course and distance, commonly called the course and distance *made good*, being the same both for Middle latitude, and Mercator sailing, we shall first give an example of the method of solving or working a traverse, without extending the solution beyond the principle of Plane sailing, and afterwards explain the more rigid mode of doing the same thing, by means of Middle latitude, and Mercator sailing.

The quantities given in a traverse, are the different courses, duly corrected for variation and leeway, and the corresponding distances. These are arranged in two separate columns of a Table, called the Traverse Table, which is furnished with two other columns, one for difference of latitude, and the other for departure, each of the last being subdivided into two others, to contain the two different denominations of difference of latitude and departure. The difference of latitude and departure belonging to each course and distance, after being obtained by inspection, are placed in their appropriate columns, indicated by the course; and the numbers inserted in each column are then added separately. The difference of the northing and southing is the difference of latitude; while the difference of the easting and westing is the departure made good, each receiving its denomination from the name of the greater sum. The corresponding course and distance made good, may be computed by Plane sailing, or found by inspection.

The construction of a traverse, in which the several courses and distances are exhibited geometrically, is effected in the following manner: Describe, in the first place, with the chord of 60°, a circle to represent the horizon; and draw through it two diameters, at right angles to each other, to denote the direction of the cardinal points. Lay off the first course and distance from the centre, considered as the point from which the ship sets out; and from the extremity of the first distance, draw a line parallel to the direction of the second course, and apply to it the length of the second distance, taken from the same scale of equal parts. Proceed in like manner, with all the remaining distances, until the whole traverse is completed. Join the centre of the circle and the remotest extremity of the last distance, and the line thus drawn will exhibit the distance made good; while the angle which it forms with the meridian will represent the course made good. The corresponding difference of latitude and departure will be the difference of latitude and departure made good.

EXAMPLE.—A ship from the Lizard Point lighthouse, bearing N.N.E. ½ E. 15 miles, has sailed on the following courses: N.E. by E. 18 miles; S.W. ½ W 24 miles; S.E. by S. 10 miles; W. 28 miles; W.N.W. 20 miles. Required her course, and distance made good.

1. *By Construction.*—Describe the arch NESW. (Fig. 23, Plate CCCCIV.) with the chord of 60°, and draw the two diameters NS and WE at right angles to each other. Then the point A being considered as representing both the centre of the compass, and the point from which the ship takes her departure, N. will be north, S. south, E. east, and W. west. The first course will be the opposite to the bearing of the Lizard Point, or S.S.W. ½ W. or 2½ points from S. Making S *b*, therefore, 2½ points by the scale of rhumbs, join A *b*, and on it lay off AB, equal to 15, taken from some scale of equal parts. The next course being N.E. by E. or 5 points, make N *c* 5 by the scale of rhumbs, and through B draw BC parallel to A *c*, and equal to 18. Again, through C draw CD parallel to the S.W. ½ W. rhumb, or 4½ points from S. towards W. and make it equal to 24. Draw, in like manner, DE parallel to the S. E. by S. rhumb, and equal to 10; EF, parallel to N.E. and equal to 28; and, lastly, FG, parallel to the W.N.W. rhumb, and equal to 20. Join AG, and AG will be the distance, and the angle GAS the course made good. Also, AH will be the difference of latitude, and GH the departure made good.

2. *By Inspection.*

Courses.	Distances.	Diff. of Lat.		Departures.	
		N.	S.	E.	W.
S.S.W. ½ W.	15	...	13.2	...	7.1
N.E. by E.	18	10.0	...	15.0	...
S.W. ½ W.	24	...	15.2	...	18.5
S.E. by S.	10	...	8.3	5.6	...
W.	28	...	...	...	28.0
W.N.W.	20	7.7	...	...	18.5
		17.7	36.7	20.6	72.1
			17.7		20.6
			19.0		51.5

It appears by the traverse table, that the difference of latitude made good is 19 miles, and the corresponding departure 51.5 miles. The course and distance made good may be found by inspection, or more accurately by calculation.

To find the course made good.

Diff. of lat. 19	1.27875
Is to the dep. 51.5 . .	1.71181
As radius	10.00000
	11.71181
To the tan. course 69° 45′,	10.43306

To find the distance made good.

Radius	10.00000
Is to sec. course . .	10.46078
As diff. of lat.	1.27875
	11.73953
To the dist. 54.95 . .	1.73953

Hence the course is S. 69° 45′ W. being W.S.W. ¼ W. nearly.

The difference of latitude and departure made good being determined as above by the principles of Plane sailing, the difference of longitude may now be found either by Middle latitude, or Mercator sailing.

By middle latitude sailing.

Lat. of Lizard Point .	49° 57′ 44″ N.
Diff. of lat.	19 0 S.
Lat. come to	49 38 44 N.
Sum of lat.	99 36 28
Half sum	49 48 14
Cos. mid. lat. 49° 48′ 14″	9.80983
Is to tan. course 69 45	10.43306
As diff. lat. 19 miles .	1.27875
	11.71181
To diff. long. 79.79 miles	1.90198

Or, without finding the course, the difference of longituge may be computed by the following analogy:

Cos. mid. lat. 49° 48′ 14″ .	9.80983
Is to radius	10.00000
As the dep. made good 51.5 miles	1.71181
	11.71181
To the diff. long. 79.79 miles	1.80198

2. By Mercator sailing.

Lat. left	49° 57′ 44″	mer. parts	3471.0
Lat. come to	49 38 44	———	3441.6
		Mer. diff. lat.	29.4

Radius . . .	10.00000
Is to tan. course 69° 45′ .	10.43306
As mer. diff. lat. 29.4 miles .	1.46835
	11.90141
To diff. long. 79.69 miles	190141

Or, without using the course, the difference of longitude may be found thus:

Diff. lat. 19 miles . .	1.27875
Is to mer. diff. lat. 29.4 miles	1.46835
As dep. made good 51.5 miles	1.71181
	3.18016
To the diff. long. 79.69 miles	1.90141

The difference of longitude is usually found, either by Middle latitude, or Mercator sailing, by means of the difference of latitude and departure made good, as in the preceding example; and it may be affirmed, that this method will always answer the purpose, to a degree of accuracy within the limits of the data from which the difference of longitude is determined, unless the distances be of great extent, or the sailing in very high latitudes. In either of these cases, however, it is necessary to have recourse to the special determination of the difference of longitude for each course and distance; and to arrange the several results in two columns, according to their denomination. The difference of the two amounts, reckoned of the same name with the greater, will be the correct difference of longitude. We shall give an example of the method of finding the difference of longitude, in the cases alluded to, both by Middle latitude and Mercator sailing.

Example.—A ship from Peterhead in lat. 57° 32′ N. long. 1° 46′ W. has sailed the following courses N.N.E. ½ E. 118 miles; N.W. by N ¾ W. 45 miles; E.N.E. 115 miles; W. by S. ¾ W. 63 miles; N.E. ¾ E. 130 miles; and W.S.W. 120 miles. In what latitude and longitude is she arrived?

1. *By Middle latitude sailing.*—In addition to the six columns usually assigned to the traverse table, it will be necessary, according to the method of solution we are now to employ, to annex four others; one for the successive latitudes; a second for the middle or mean latitudes; and the remaining two for the resulting differences of longitude, which, after being found by inspection, must be disposed in their respective columns, as indicated by the course.

Traverse Table.						*Longitude Table.*			
Courses.	Dist.	Diff. of Lat.		Dep.		Successive Latitudes.	Middle Latitudes.	Diff. of Long.	
		N.	S.	E.	W.			E.	W.
						Deg. Min.	Deg. Min.		
						57 32			
N.N.E. ½ E.	118	104.1		55.6		59 16.1	58 24	106.2	
N.W. by N. ¾ W	45	33.3			30.2	59 49.4	59 37.7		59.7
E.N.E.	115	44.0		106.3		60 33 4	60 11.4	213.8	
W. by S. ¾ W.	63		3.1		62.9	60 30.3	60 31.8		127.9
N.E. ¾ E.	130	77.4		104.4		61 47.7	61 9	216.4	
W.S.W.	120		45.9		110.9	61 1.8	61 24 7		231.8
		258 8	49.0	266 3	204.0			536.4	419.4
		49.0		204.0				419.4	
		209.8		62.3				117.0	

Lat. of Peterhead 57° 32′ N. Long. 1° 46′ W.
Diff. of lat. 3° 29′.8 N. Diff. of long. 1° 57′ E.

Lat. come to 61° 1′.8 N. Long. in 0° 11′ E.

If the difference of longitude be found in the usual way, that is, by the mean of the latitude left and the latitude come to, with the departure made good, it will be found 122′, differing 5′ from the difference of longitude, determined more correctly by the method of successive latitudes.

2. *By Mercator sailing.*—The traverse table being completed in the common form, the longitude table must be furnished with three columns, referring more immediately to Mercator sailing, viz. one for successive latitudes, a second for meridional parts, and a third for meridional differences of latitude. The difference of longitude column is divided, as before, into two subordinate columns.

The table being thus furnished with all the necessary columns, it only remains to fill up the easting and westing of the longitude columns, by means of the several courses, and the corresponding meridional differences of latitude.

Longitude Table.

Success. Latitudes.	Meridional Parts.	Meridional Diff. Lat.	Diff. of Long.	
			E.	W.
57° 2′	4241.8			
59 16.1	4440.6	198.8	106.3	
59 49.4	4506.3	65.7		59.5
60 33.4	4594.7	88.4	213.4	
60 30.3	4588.4	6.3		129.1
61 47.7	4748.8	160.4	216.3	
61 1.1	4653.0	95.8		231.3
			536.0	419.9
			419.9	
			116.1	

Long. of Peterhead . 1° 46′ W.
Diff. of long. . . 1° 56′.1 E.

Long. in . . 0° 10′.1 E.

We shall conclude the subject of Traverse Sailing, by remarking, that if the ship has sailed, during the whole time she has taken to complete the traverse, in a current, the setting and drift of which are known, the setting of the current must be inserted among the courses, and the product of its drift per hour by the number of hours the ship has been exposed to it, as the corresponding distance. A similar allowance must be made for the direction of a swell of sea, and the drift which it occasions.

Sect. VI. *Oblique Sailing.*

Oblique Sailing is chiefly employed in marine surveying, and the solution of such nautical problems as are connected with coasting, and the calculation of the distances of visible objects. In these cases, the surface of the earth may be regarded as an extended plane, without leading to any error of sufficient magnitude to affect the practical results derived from that supposition.

The problems which admit of being solved by Oblique sailing, or rather by the application of Oblique Plane Trigonometry, may be greatly diversified; but we shall endeavour to reduce the most useful and important of them under a few general cases.

Case I. *To determine the distance between two objects, one of which is accessible.*

Method.—Measure a base-line running from the accessible object, in any direction except a straight line, either from or towards the other object; and at each extremity of the base-line, take the angles which it forms with imaginary lines proceeding to that object, either by means of the compass, or Hadley's sextant.

Example.—Sailing along a coast, I took the bearing of a lighthouse, and found it N. N. E. $\frac{1}{2}$ E.; I then ran $6\frac{1}{2}$ miles on a N. E. by E. course, after which I observed it to bear N. W. $\frac{1}{2}$ W. What was the distance of the lighthouse at the last time of setting it?

1. *By Construction.*—Describe a circle, with the chord of 60° to represent the horizon, and draw the cardinal lines N. S. and W. E. at right angles to each other. Then, A being supposed the ship's place when the bearing of the lighthouse was first observed, draw AL, making with AN an angle of $2\frac{1}{2}$ points. Next, draw AB, making with AN an angle of 5 points, and make AB equal to 6.5 by some scale of equal parts. Lastly, through B draw BL, parallel to the N. W. $\frac{1}{2}$ W. rhumb, and the point L will be the position of the lighthouse; so that if BL be applied to the same scale from which AB was taken, the distance BL will be found 3.12 miles.

2. *By Calculation.*—In the triangle ABL are given $AB = 6\frac{1}{2}\,m$; angle $ABL =$ angle $b\,A\,l =$ angle $W\,A\,b +$ angle $W\,A\,l = 3\,p + 3\frac{1}{2}\,p = 6\frac{1}{2}\,p$; and angle $BAL = 5p - 2\frac{1}{2}\,p = 2\frac{1}{2}\,p$. Hence, angle $ALB = 16p - \overline{6\frac{1}{2} + 2\frac{1}{2}} = 16\,p - 9\,p = 7$ points.

To find BL.

Sine angle ALB $7\,p$.	9.99157
Is to sine angle BAL $2\frac{1}{2}\,p$	9.67339
As AB $6.5\,m$ . .	.81291
	10.48630
To BL 3.124 miles .	.49473

Hence the distance is $3\frac{1}{8}$ miles.

In approaching a coast, of which the mariner is in possession of a good chart, this case may be applied to the determination of the distance of a ship from any two objects laid down in the chart, by simply observing the bearing of each, and then deducing from these data, and the mutual bearing of the objects on the chart, the three angles of a triangle, the given side of which is the distance of the objects on the chart. It may also be used with great advantage in laying down soundings, rocks, &c. in marine surveying, after an accurate delineation has been made of the position and bearing of the principal objects to be introduced in a chart.

Example.—Approaching a coast from sea, a good chart of which I had in my possession, I took the bearing of a steeple and a lighthouse, which I found by the chart lay S. E. and N. W. of each other, the distance between them being $5\frac{1}{4}$ miles. What was my distance from the steeple and the lighthouse, at the time of observation, the former having bore W. S. W. $\frac{1}{2}$ W., and the latter S. S. W. $\frac{3}{4}$ W.?

1. *By Construction.*—Describe a circle with the chord of 60°, and draw, as before, the two diameters N. S. and W. E. at right angles to each other. From A, repre-

senting the place of the steeple, draw AB = the S. E. rhumb, and make it equal to 5.25, by some convenient scale of equal parts. From A, draw AC in the opposite direction to the bearing of the steeple, that is, E. S. E. ½ E. and through B, representing the position of the lighthouse, draw BC also in an opposite direction to its bearing, or parallel to the N. N. E. ¾ E. rhumb. The intersection of AC and BC will give the point C, the position of the ship; so that AC and BC being applied to the same scale from which AB was taken, their lengths will give the distance of the steeple and the lighthouse from the ship.

2. *By Calculation.*—In the triangle ABC are given the side AB 5.25; angle BAC, the angle contained by the rhumbs S. E. and E. N. E. ½ E. being 4 p. + 1½ p. or 5½ points; angle ACB, the angle contained by the rhumbs W. S. W, ½ W. and S. S. W. ¾ W. being 6½ p. —2¾ p. or 3¾ points; and lastly, the angle ABC, the difference between 16 p. and the sum of the angles BAC and ACB, being 16 p.—9¼ p. or 6¾ points. This last angle might also have been found by taking the angle contained by the rhumbs N. W. and N. N. E ¾ E. being 4 p. + 2¾ p. or 6¾ points, as before.

To find AC, the distance of the steeple.

Sine angle ACB 3¾ p. .	9.82708
Is to sine angle ABC 6¾ p.	9.98679
As AB 5.25 m. . .	0.72016
	10.70695
To AC 7.583 m. . .	0.87983

To find BC, the distance of the lighthouse.

Sine angle ACB 3¾ p. .	9.82708
Is to sine angle BAC 5½ p.	9.94543
As AB 5.25 . . .	0.72016
	10.66559
To BC 6.852 m . .	0.83851

Case II.—*To determine the distance between two objects, both of which are inaccessible.*

Method.—Measure a base line, from each extremity of which both objects are at the same time visible, and take the angles which this line makes with the lines running to each object.

Example.—Sailing along an unfrequented coast, I observed two remarkable promontories C and D, whose distance I resolved to determine. Having taken the bearing of each, I found C bore N. ½ E. and D, W. N. W. ¾ W. I then ran 12 miles on a S. W. by W. course, after which I observed C bore N. E. ¼ E. and D, N. W. by N. ¼ W. Required the distance of the two promontories from each other?

1. *By Construction.*—Describe a circle with the chord of 60°, and draw, as before, the two diameters N. S. and W. E. at right angles to each other. From A representing the ship's place when the bearing of the objects were first taken, draw AB, making with AS an angle of 5 p. and equal to 12 by some scale of equal parts; through A draw also AC, making with AN an angle of ½ p. and AD, making with the same line an angle of 6¾ p. Lastly, through B draw BC and BD parallel, respectively, to the N. E. ½ E. and N. W. by N. ½ W. rhumbs, and DC will be the distance required.

2. *By Calculation.*—The calculation may be conducted in two ways: AC may be found in the triangle ABC, and then AD in the triangle ABD, after which two sides of the triangle CAD would be given, together with the contained angle CAD, from which the third side BC could be determined; or, BC may be found in the first of these triangles, and BD in the second, after which two sides of the triangle BDC would be given, together with the contained angle, from which BC could be determined as before. We shall employ the former of these ways.

In the triangle ABC are given AB = 12 m. angle BAC = ½ p. + 8 p. + 5 p. = 13½ p. angle ABC, the angle contained by the rhumbs N. E. by N. and N. E. ½ E. or 1½; consequently the remaining angle ACB is 1 point.

Again, in the triangle ABD are given AB = 12 m. angle BAD 6¼ p. angle ABD, the angle contained by the rhumbs N. W. by N. ½ W. and N. E. by N. the opposite to S. W. by S. being 6½ p. consequently the remaining angle ADB is 3¼ points.

Also the angle CAD is 6¾ p. + ½ or 7¼ points.

To find the side AC.

Sine angle ACB 1 p. .	9.29024
Is the sine angle 1½ p. .	9.46282
As AB 12 . . .	1 07918
	10.54200
To AC 17.855 . .	1.25176

To find the side AD.

Sine angle ADB 3¼ p. .	9.77503
Is to sine angle ABD 6½	9.98088
As AB 12 . . .	1.07918
	11.06006
To AD 19.277 . .	1.28503

To find the angles ACD and ADC.

Sum of AC and AD 37.132 .	1.59974
Is to their difference . .	.15290
As tan. ½ sum op. angles $\frac{16 - 7\frac{1}{4}}{2}$ or 4⅜ p. $\Big\}$ = 49° 13′	10.06416
	10.21706
To tan. $\frac{ACD - ADC}{2}$ 2° 32′½ .	8.64732

Hence angle ACD = 49° 13′ + 2° 32′½ = 51° 45′½.
angle ADC = 49° 13′ — 2° 32′½ = 46° 40′½.

To find DC.

Sine angle ADC 46° 40′½	9.86182
Is to sine angle CAD 7¼ p.	9.99527
As AC 17.855 . .	1.25176
	11.24703
To DC 24.28 m. . .	1.38521

Case III.—*Giving the bearing and distance of a port to windward, and the direction of the wind, to find the distance a ship must sail, on each of two tacks, to reach the port by the nearest method.*

Method.—Having laid down the ship's place, and the position of the port, draw, through the points by which they are represented, two straight lines parallel to the rhumbs on which the ship can sail on each tack, according to the wind; and their intersection will be the point at which she must be brought from the first to the second tack.

Example.—A ship which can lie within $6\frac{1}{4}$ points of the wind, is bound to a port 21 miles off, bearing N. N. E. $\frac{1}{2}$ E. what distance must she run, on each of two tacks, to reach the port, the wind being N. by E.

1. *By Construction.*—About the point A, (Fig. 26. Plate CCCCIV.) representing the ship's place, describe a circle with the chord of 60°, and draw the diameters N. S. and W. E. intersecting each other at right angles. From A, draw AB in the directions of N. N. E. $\frac{1}{2}$ E. and having made it equal to 21, the point B will be the intended port. If the first tack is to be with the larboard tacks on board, from A draw AC, making, with DA, the direction of the wind, an angle of $6\frac{1}{4}$ points, or coinciding with the rhumb E. by N. $\frac{1}{4}$ E. Next, from D lay off DF $6\frac{1}{4}$ points, and through B draw BC parallel to FA, and C will be the point where the ship must tack.

2. *By Calculation.*—In the triangle ABC are given AB = 21 m.; angle BAC = $7\frac{1}{4}$ p.—$2\frac{1}{2}$ p. = $4\frac{3}{4}$ points; angle ACB = angle GAF = $2\frac{3}{4}$ p. + $\frac{3}{4}$ p. = $3\frac{1}{2}$ points; and therefore the remaining angle ABC = 16 p. — ($4\frac{3}{4}$ p. + $3\frac{1}{2}$ p.) = 16 p. — $8\frac{1}{4}$ p. = $7\frac{3}{4}$ points.

To find AC.

Sine angle ACB $3\frac{1}{2}$ p. .	9.80236
Is to sine angle ABC $7\frac{3}{4}$ p.	9.99948
As AB 21	1.32222
.	11.32170
To AC 33.06 m. . .	1.51934

To find BC.

Sine angle ACB $3\frac{1}{2}$ p. .	9.80236
Is to sine angle BAC $4\frac{3}{4}$ p.	9.90483
As AB 21	1.32222
	11.22705
To BC 26.59 m. . .	1.42469

If the first tack had been made with the starboard tacks on board, it would have been 26.59 miles, and the second 33.06 miles.

Case IV.—*Given the course and distance by account, and the drift and setting of a current, to find the course and distance made good.*

Method.—If a body be under the simultaneous influence of two motions, or two solicitations to motion, it is demonstrable, on the principles of mechanics, that it will, in these circumstances, describe the diagonal of a parallelogram, the sides of which represent the directions and magnitudes of the two motions. Hence, if a ship sail in a known current, her course and distance made good will be determined by the direction and magnitude of the diagonal of a parallelogram, of two adjacent sides of which, one represents the ship's apparent course and distance, and the other the drift and setting of the current during the same time.

Example.—A ship running at the rate of $6\frac{1}{2}$ miles per hour, apparently in a S. S. W $\frac{1}{2}$ S. course, finds she has been sailing five hours in a current setting N. W. by W. $\frac{1}{2}$ W. $2\frac{1}{4}$ miles per hour: What was her actual course and distance?

Apparent distance = 6.5 × 5 = 32.5 miles.
Drift of current = 2.25 × 5 = 11.25 miles.

1. *By Construction.*—Having described the circle N. W. S. E. representing the horizon, as in the preceding examples, through A draw AC, a S. S. W. $\frac{1}{2}$ S. rhumb, and make A equal to 32.5, by some scale of equal parts. Next, through A draw AD, a N. W. $\frac{1}{2}$ W. rhumb, and equal, by the same scale, to 11.25. Complete the parallelogram ABCD, by drawing CD parallel to AB, and BC parallel to AD; join AC, and AC will be the distance, while angle CAS will be the course made good.

2. *By Calculation.*—In the triangle ABC are given AB = 32.5. m. BC = AD = 11.25 m. and angle ABC = angle DAF = angle DAN + angle NAF = $5\frac{1}{2}$ p + $1\frac{1}{2}$ p = 7 points.

To find the angles ACB and BAC.

$$\text{Angle}\ \frac{ACB + \text{angle } BAC}{2} = \frac{16\text{ p.} - 7\text{ p.}}{2} = \frac{9\text{ p.}}{2}$$

$$= 4\tfrac{1}{2}\text{ points} = 50^\circ\ 37'\tfrac{1}{2}.$$

The sum of AB and BC 43.75 .	1.64098
Is to their difference 21.25 .	1.32736
As tan. $\frac{ACB + BAC}{2}$ 50° 37′$\frac{1}{2}$	10.08583
	11.41319
To tan. $\frac{ACB - BAC}{2}$ 30° 37′ 8″	9.77221

Hence angle ACB = 50° 37′ 30″ + 30° 37′ 8″ = 81° 14′ 38″.
angle BAC = 50° 37′ 30″ — 30° 37′ 8″ = 20° 0′ 22″.

So that the course made good, viz. angle CAS = $1\frac{1}{2}$ p. + 20° 0′ 22″ = 16° 52′ 30″ + 20° 0′ 22″ = 36° 52′ 52″, being about $3\frac{1}{2}$ points, or S. W. by S. $\frac{1}{2}$ W. nearly.

To find AC, the distance made good.

Sine angle BAC 20° 0′ 22″	9.53418
Is to sine angle ABC, 7 p.	9.99157
As BC 11.25 m. . .	1.05115
	11.04272
To AC 32.25 m. . .	1.50854

When a ship sails in a current, her course and distance made good may be found by means of a traverse, the setting and drift of the current being inserted as a course and distance, and computed for accordingly, in the following manner:

Traverse Table.

Courses.	Dist.	Diff. Lat.		Dep.	
		N.	S.	E.	W.
S. S. W. ½ S.	32.5	5.3	....	....	9.5
N. W. by W. ½ W.	11.25	....	31.1	....	9.9
		5.3	31.1		19.4
			5.3		
			25.8		

To the diff. of lat. 25.8, and dep. made good 19.4, the course is S. 37° W. and the distance 32.3 miles.

CHAP. IV.

Of the Construction and Use of Sea Charts.

The position of places, however accurately determined by their latitude and longitude, can be very imperfectly conceived, without the aid of a visible representation of their mutual bearings and situation. A map, or chart, by exhibiting a reduced but faithful delineation of the boundaries of land and water—of the outlines of islands, bays, and headlands—and of the various natural objects on the surface of the globe, whose magnitude is such as to admit of geometrical representation, conveys a more accurate notion of form and position than can be derived from the most minute and laboured description. Hence it is of the utmost importance to the mariner, to be furnished not only with a correct and extensive table of the latitudes and longitudes of places, but also with accurate maps or charts of all the more remarkable harbours, bays, and creeks, which he may, either from choice or necessity, have occasion to visit.

The charts employed for nautical purposes are of two descriptions: one of these is used to find the course and distance between two places considerably remote from each other, as well as to give notice of the cases in which it is impracticable to sail on the course and distance found by calculation from geographical position; the other is intended to guide the seaman in his approach to his destined port, or place of shelter, and to point out various local circumstances connected with it, without the knowledge of which, it would frequently be hazardous to attempt to enter it. Charts, having the latter object in view, embrace but a small portion of a coast, and are generally constructed on the supposition, that the surface of the earth is an extended plane; whereas, when they are used for the former purpose, they must be projected on principles consistent with the spherical form of the earth, and the exhibition of its surface on a plane. Hence nautical charts are divided into Plane charts and Mercator charts, each of which we shall consider in order.

SECTION I. *Of Plane Charts.*

The Plane Chart, being constructed on principles which, if they were followed out on a large scale, would lead to considerable errors in the representation of the position of places, is confined entirely to the delineation of harbours, small bays, or limited portions of coast. The importance, however, of such charts, when they are duly restricted in point of extent, demands a particular explanation of the methods which ought to be observed, for obtaining the elements requisite to construct them in an accurate and expeditious manner.

No survey whatever can be conducted with sufficient precision without an instrument for measuring lines, and another for taking angles; but to these must be added, in marine surveying, a lead, for delineating the depth of water at all the remarkable points included in the chart.

Before proceeding to the measurement of a single line or angle, the outline of the harbour or bay should be carefully examined, and every prominent point noted by the erection of a pole, or other fixed mark, capable of being recognized at a distance. The subsequent deleneation will also be greatly assisted by as accurate an eye-sketch of the whole as can be obtained by connecting together the different points at which the poles have been set up. By means of this eye-sketch, and the general character of the outline, it will, for the most part, be easy to fix on two stations, from each of which the different poles are visible. Let the distance between these two stations, represented by A and B, be carefully measured in feet, by help of a chain, or other measure of length; and then at A take, either with an azimuth compass, or Hadley's quadrant, all the angles formed by the base-line AB, and imaginary lines running to the different poles, C, D, E, F, G, &c. Proceed next to the station B, and at that point take, in like manner, all the angles formed by BA, and imaginary lines running from B to each of the poles. There will thus be obtained by measurement, in each of the triangles ABC, ABD, ABE, &c. a side, and all the angles, from which the remaining two sides, and consequently the position of the points C, D, E, &c. may be determined either by calculation or construction. The position of any rock or island R, may be laid down in the same manner.

If all the remarkable points to be included in the survey, are not visible from each of the stations A and B, a new base-line, as AB′, must be connected with the former, by measuring the angle BAB′, and then the angles at each of the stations A and B′, as before. After which the intermediate points are to be laid down, partly by measurement, and partly by the eye, according to their importance in the intended chart. Before removing, however, from the stations A and B, it will be proper to lay down, by means of the base-line AB, the position of any steeple, tower, or other remarkable object of a permanent nature, which may serve as a landmark at sea; and also to fix the position of the base-line in reference to the true meridian. The last object will be most easily attained by observing the angle which the direction of the sun makes with the base-line at his rising or setting, and then to compute the bearing by the method of determining his amplitude, to be afterwards explained under NAUTICAL ASTRONOMY. If the variation is known, the true meridian may be ascertained at once by the azimuth compass. The position of the meridian, in whatever way it is determined, must be connected with some known line in the survey, by means of which it may be afterwards exhibited in the chart.

After a sufficient number of measurements have been taken for laying down the position of every land object to be represented in the chart, it next becomes necessary to fix the nature, bearings, and positions of objects at sea, such as the depth of water, the quality of the bottom or ground, the direction and rate of the tide of flood, &c

Having procured a boat, therefore, with proper sounding lines, let her be rowed backward and forward during the time of low water, and at every point where soundings are taken, observe, by means of an azimuth compass, the bearings of each of the stations A and B, or of any two other objects, whose position has been fixed in reference to the original base-line. At each point of observation the quality of the ground, whether rocky, muddy, sandy, or of any other description, must be marked in an appropriate manner on the sketch, in order that it may afterwards be transferred to the chart, together with the depth of water, and any other local circumstance of importance to be known.

The survey being completed, it only remains to apply the different measurements, on a suitable scale, to paper, so as to give a proper delineation of the appearances of the shores, whether bold and precipitous, or low lying and shoaly; of the outlines of isles, rocks, sands, &c. according to their several positions; of the best anchoring places, with their soundings at low water; of the land-marks to be observed for avoiding sunk rocks, shallows, &c. of the setting and drift of currents, and the time of high water on the days of new and full moon. It may be proper also to lay down the situation of the most convenient places for obtaining a supply of fresh water, if there are any such within the limits of the survey, together with any thing else of a topical nature, which can add to the value of the chart. A compass must also be inserted in some part of the chart, where the representation of it will not interfere with the rest of the delineation; and lastly, a scale of nautical miles, duly subdivided, by allowing 6076 feet to a mile. It is scarcely necessary to add, that the north and south line of the compass must either be parallel to, or coincide with the true meridian; and that, in laying down the different bearings taken with the azimuth compass, all of them must be corrected for variation before they are applied to the chart.

With respect to the manner of representing the different objects usually exhibited in a chart, it is not easy to give directions which can be rendered intelligible without a reference to a particular delineation; but it may be remarked in general, that most of the objects are so represented as to bear some kind of resemblance to their actual appearance in nature, as far as that can be done, in conformity with their supposed projection on a horizontal plane. Thus, in Fig. 28, Pl. CCCCIV. No. 1, represents a low sandy shore; No. 2, a bold rocky coast; No. 3, a rock always above water; No. 4, rocks covered at high water, but dry at low water; No. 5, rocks always below water; No. 6, sand banks dry at low water, but covered each tide; No. 7, sand banks always under water; No. 8, good anchoring ground; No. 9, where a ship may ride occasionally; No. 10, the safest channel; No. 11, the setting of flood tide; No. 12, an eddy; No. 13, a whirlpool; No. 14, a beacon; No. 15, a buoy.

A survey of a coast, made by sailing along it, must necessarily be conducted with a less scrupulous attention to the position of the subordinate points in the outline. All that can be done in such cases is to determine the geographical position of the more prominent objects of the survey, such as the mouths of rivers, headlands, bays, creeks, &c. by means of the first and second cases in Oblique Sailing. Their latitudes and longitudes may then be deduced from the latitude and longitude of the ship, found by celestial observation.

With regard to the manner of using a plane chart, for the purposes to which it is commonly, and almost exclusively applied, few directions can be necessary. The object of the chart being chiefly to point out the best way of entering a bay, creek, harbour, &c. and to indicate the position of the safest anchoring ground within it, the ship must be guided in the former case by the direction of the tracks referred to in No. 10. Fig. 29. Pl. CCCCIV. and in the latter by the bearing from the ship of two objects laid down in the chart. These objects should be selected, so that their respective bearings may not make with each other a very acute angle, both being duly corrected for variation, in order that their actual bearing in reference to the ship's place at the time of setting the objects, may be accurately ascertained in the chart. Lines drawn through each of the objects, in an opposite direction to that of their corrected bearings from the ship, will determine, by their intersection, the ship's place on the chart, and consequently render it easy to find afterwards the true course and distance to the intended anchoring ground.

SECTION II. *Of Mercator Charts.*

The method of constructing charts, on the principle of Mercator's projection, has been already so fully explained under the article GEOGRAPHY, that it is altogether unnecessary to resume the subject in this place. We shall therefore deem it sufficient to state, that after the meridians and parallels of latitude have been correctly drawn, and the graduation extended to a necessary degree of minuteness at the sides, as well as at the top and bottom of the chart, the next object is to lay down every remarkable place, promontory, bay, &c. according to its latitude and longitude, taken from the most authentic tables. This is easily done by means of the intersection of a meridian passing through the longitude at the top and bottom, and a parallel of latitude passing through the latitude, at the sides of the chart. The outline of the coast between two places whose position is laid down in the chart, must be supplied from plane charts, if these can be procured, or, in the absence of other information, from the best maps already extant. Lastly, from some point of the chart, as a centre, the several rhumb lines must be drawn with the utmost accuracy; and if the projection be on a very large scale, it may be necessary to have recourse to more than one point for that purpose. Having made these general observations on the construction of a Mercator chart, we shall now explain the manner of using it, for solving the more important cases in geographical navigation.

PROBLEM I.

To find the course and distance between two given places on the chart.

CASE I. *When the two places are under the same meridian.*

The difference of the latitudes, found in the ordinary way, and reduced to minutes, is their distance in nautical miles.

CASE II. *When the two places are on the same parallel.*

This case can be solved on the map only by approximation. It is better therefore to convert the difference of longitude into meridional distance, by parallel sailing, than to employ for that purpose a mechanical method equally tedious, and much less correct.

CASE III. *When the two places are under different meridians, and on different parallels of latitude.*

Draw, with a black lead pencil, a straight line from one of the places to the other, and also through the place from which the distance is to be estimated, a meridian line. From this place lay off on the meridian line the difference of latitude between the two places, taken from the equator, or graduated parallel at the top or bottom of the chart; and lastly, through the point to which this distance extends on the meridian, draw a line parallel to the nearest parallel of latitude. The distance between the point where this line intersects the line joining the two places, and the place from which the distance is to be reckoned, being applied to the graduated parallel at the top or bottom of the projection, will give, in degrees and minutes, the distance; and these degrees and minutes being reduced to minutes, will be the distance in nautical miles.

PROB. II.

Given the latitude sailed from, with the course and distance, to find the ship's place on the chart.

CASE I. *When the course is due north or south.*

The distance being reduced to degrees and minutes, and added to, or subtracted from, the latitude left, according as the ship has been increasing or decreasing her latitude, the sum or difference will be the latitude come to; a parallel through which, on the chart, will intersect the meridian the ship has sailed on, in a point corresponding to her place.

CASE II. *When the course is due east or west.*

Reduce the distance to difference of longitude, by parallel sailing, and then lay off the result, taken from the graduated parallel at the top or bottom of the chart, along the parallel of the ship's latitude. The point to which it extends will be the ship's place.

CASE III. *When the course is oblique to the meridian.*

From a point in the chart, denoting the place sailed from, draw, with a black lead pencil, a line parallel to the rhumb of the ship's course, and, having taken the distance from the graduated parallel, lay it off on the line representing the direction in which the ship has sailed. From the point to which the distance extends, describe a parallel of latitude intersecting the meridian, drawn through the place sailed from. Take the distance of this parallel from the place sailed from, and apply it to the graduated parallel. The degrees, &c. intercepted will be the difference of latitude. The latitude come to being thus known, the point where the corresponding parallel intersects the distance produced, will be the ship's place on the chart.

The other problems in Mercator sailing may be solved, in like manner, on the chart; but the two which we have given are sufficient to illustrate the principles of the method to be observed in other cases. They are also the only problems usually solved on the chart.

CHAP. V.

Of the Methods of finding the Time of High Water.

In the last chapter, we explained the construction and use of sea charts; we now propose to take a practical view of those great periodical fluctuations in the waters of the ocean, denominated the tides, without a knowledge of which, the most accurate charts would, on many occasions, not only prove useless, but be liable to mislead.

The phenomena, as well as the causes of the tides, have been amply described and explained under the article ASTRONOMY. That these alternate elevations and depressions of the ocean are owing to the joint influence of the sun and moon, more especially of the latter body, is a physical fact, so well established, and so consistent, in every respect, with the demonstrable effects of universal gravitation, that the state of the tides can easily be determined, at any time, from the relative position of these two great luminaries. The greatest elevation of the water takes place in different situations, a longer or a shorter period after the moon has passed the meridian; but this interval being once known, the time of high water may be computed from the moon's age, with a degree of accuracy sufficient for all nautical purposes.

If the moon's motion in her orbit were uniform, and the distance of the sun from the earth considerably greater, the tides would succeed each other nearly at equal intervals, and with the same regularity, every lunation. In consequence, however, of the numerous anomalies to which the moon's motion is subject, and the attractive influence which she exerts on the waters of the ocean, being sometimes aided, and sometimes counteracted, by the action of the sun, the interval between successive tides is extremely variable. The following table, from M. de La Caille, exhibits the retardation of the tides, corresponding to the different states of the moon's age, and being used with the time of high water at the full and change, will point out the time of high water, at any place where the former time is known, so as seldom to deviate many minutes from the truth. The correction to be applied is adapted to every six hours of difference in the moon's age; but it must be increased by 12 hours after full moon. Thus the correction, when the moon's age is 20 days 6 hours, is 15 hours 21 minutes.*

Correction to be applied to the time of High Water, at Full and Change.

Moon's Age.		Correction.		Moon's Age.		Moon's Age.		Correction.		Moon's Age.	
Days.	Hours.	H.	M.	Days.	Hours.	Days.	Hours.	H.	M.	Days.	Hours.
0	0	0	0				12	5	6		6
	6		8	15	0		18		22		12
	12		17		6	8	0		40		18
	18		26		12		6	6	0	23	0
1	0		36		18		12		20		6
	6		45	16	0		18		39		12
	12		54		6						
	18	1	2		12	9	0		58		18
2	0		11		18		6	7	18	24	0
	6		19	17	0		12		37		6
	12		28		6		18		56		12
	18		37		12	10	0	8	14		18
							6		31	25	0
3	0		46		18		12		47		6
	6		54	18	0		18	9	2		12
	12	2	3		6	11	0		17		18
	18		12		12		6		31	26	0
4	0		21		18		12		44		6
	6		30	19	0		18		56		12
	12		40		6						
	18		50		12	12	0	10	9		18
5	0	3	1		18		6		21	27	0
	6		11	20	0		12		32		6
	12		21		6		18		43		12
	18		32		12	13	0		53		18
							6	11	3	28	0
6	0		44		18		12		13		6
	6		56	21	0		18		23		12
	12	4	9		6	14	0		33		18
	18		23		12		6		42	29	0
7	0		37		18		12		51		6
	6		51	22	0		18	12	0		12

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* A method of determining very correctly the time of high water has been just published by General Sir Thomas Brisbane, in the *Edinburgh Philosophical Journal*, vol. iv. p. 54.

The two elements to be used with this table for determining the time of high water are the moon's age, and the time of high water at full and change, at the place for which the calculation is made. The latter is an object of observation, and is generally inserted in elementary works on navigation, with the latitude and longitude of places; the former is ascertained with the utmost accuracy by a method which we have explained in Astronomy. In the present case, however, very great accuracy is not necessary, it being quite sufficient for the purpose to find the moon's age within a few hours of the truth, as the problem, from its nature, does not admit of being solved with perfect precision, on account of the contingent causes by which the tides are occasionally retarded or accelerated. In finding the moon's age, therefore, we shall employ only one argument, the sun's anomaly; the corresponding equation to be applied to the time of the mean new moon in March, laid down in Table I. Astronomy, being generally fitted to give the time of new moon, within a few hours of what would be obtained by the most rigid calculation.

Prob. I.—*To find the Time of New Moon nearly.*

When the new moon is sought for March, or any of the following months, write out from Table I. Astronomy, the time of mean new moon in March for the given year, and also the sun's mean anomaly in the right hand column of the table; but if the new moon is required for January or February, these quantities must be taken for the preceding year. Take next from Table III. as many mean lunations as, with the time of new moon for March, may be equal to some of the numbers, under the given month in Table IV. and add the corresponding anomaly of the sun, in the right hand column of the table, to his anomaly formerly found. The number on the left hand of Table IV. corresponding to the sum of the lunations and the mean new moon in March, is the day of the month, and must be placed before the hours, minutes, &c. of that sum. Add to or subtract from the time thus found, according as the sign is + or — the equation in Table VII. corresponding to the sum of the two anomalies, rejecting 12 signs if the sum of the anomalies exceeds that number, and the sum or difference will be the time of new moon nearly.

Example I.—Required the time of new moon for September 1821.

	D.	h.	m.
Mean new moon in March, 1821,	3	10	27
Seven lunations from Tab. III.	206	17	8
	210	3	35
Sun's anomaly in Tab. I.	8s.	1°	31′
———— in Tab. III.	6	23	44
Sum, rejecting 12 signs,	2	24	15

Opposite to 210, in Table IV. is 26 days.

	D.	h.	m.
Hence approximated time of new moon is Sept.	26	3	35
Equation to 2s. 24° 15′ in Table VII.	—	3	46
Time of new moon nearly,	25	23	49

Example II.—Required the time of new moon in January, 1821.

	D.	h.	m.
Mean new moon in March 1820,	14	1	39
10 mean lunations, Tab. III.	295	7	20
	309	8	59
Corresponding sun's anomaly	8s.	12°	15
————————	9	21	3
Sum, rejecting 12s.	6	3	18

Opposite to 309, in the left hand column of Table IV. is 3.

	D.	b.	m.
Hence the approximate time of new moon is January,	3	8	59
Equation for 6s. 3° 18′, Table VII.	+	0	13
Time of new moon in Jan. nearly,	3	9	12

Hence the time is 18 m. past 3 o'clock P. M. of January 6.

These calculations, though of an approximated nature, being adapted to the meridian of Greenwich, if the place for which the calculation is made be under a different meridian, a correction must be made for the difference of longitude, in all cases where that difference would materially affect the result. If the longitude be east from Greenwich, the calculated time of new moon must be increased an hour for every 15° of difference of longitude, but diminished in the same proportion, if the longitude be of an opposite denomination.

Example.—What is the time of new moon in October, 1830, at Bridgeton, Barbadoes, in Long. 59° 41′ W

Mean new moon, March, 1830,	23	20	40
Six mean lunations, Table III.	206	17	8
	230	13	48
Corresponding suo's anomaly,	8s.	21°	19
————————	6	23	44
Sum, rejecting 12s.	3	15	3

Opposite to 230, in the left hand column of Table IV. is 16.

	D.	h.	m.
Hence the approximate time of new moon at Greenwich is, Oct.	16	13	48
Equation from Tab. VII. for 3s. 15° 3′,	—	3	41
Time of new moon at Greenwich nearly,	16	10	7
Diff. of long. in time for given place,		4	59 W.
Time of new moon at Bridgeton,	16	5	8

Hence the time is 8 m. past 5 o'clock P. M. of Oct. 16.

Prob. II.—*To find the moon's age, for the noon of a given day, at a given place.*

Find, by the last problem, the time of the preceding change, and then subtract the days, hours, &c. corresponding to it, from the given day of the month, reckoned forward from the time of new moon.

Example I.—What is the moon's age at Port Royal, Jamaica, for the noon of May 25, 1840?

	D.	h.	m.
Mean new Moon, March, 1840,	3	2	58
Two mean lunations, Table III.	59	1	28
	62	4	26
Corresponding sun's anomaly,	8s.	1°	16′
————————	1	28	13
	9	29	29

The number opposite to 62, on the left hand column of Table IV. is 1.

	D.	h.	m.
Hence the approximate time at Greenwich is, May	1	4	26
Equation for 9s. 29° 29′ in Table VII.	+	3	16
Time of new moon in May, at Greenwich	1	7	42
Diff. of long. in time for 76° 45′	0	5	7 W.
Time of new moon at Port Royal in May	1	2	35
Given day,	25	0	0
Moon's age at Port Royal, noon of May 25, 1840,	23	21	25

Required the moon's age for the noon of February 18, 1837, at Batavia, in Long. 106° 52′ E.

	D.	h.	m.
Mean new moon, March, 1836,	17	3	0
11 mean lunations, Tab. III.	324	20	4
	341	23	4
Corresponding sun's anomaly	8s.	15°	6′
————————	10	20	10
Sum, rejecting 12s.	7	5	16

Opposite to 341, on the left hand column of Table IV. is 4.

	D.	h.	m.
Hence the approximate time at Greenwich is, Feb.	4	23	4
Equation for 7s. 5° 16′ in Tab. VII. . .	+	2	14
Time of mean new moon at Greenwich, .	5	1	18
Diff. of long. in time for 106° 52′ . .	0	7	7 E.
Time of new moon at Port Royal, . .	5	8	25
Given day, ...	18	0	0
Moon's age at Batavia, noon of Feb. 18, 1837,	12	15	35

Prob. III.—*To find the time of High Water on a given day, at a place where the time of High Water at full and change is known.*

Find, by the last problem, the moon's age on the given day, at the proposed place. Take the corresponding correction from the table, and add it to the time of high water at full and change; the sum will be the time of high water on the given day. If the sum exceeds 12½ hours, subtract the allowance for a tide, according to the moon's age, found in the above table; and if it exceeds 25 hours, subtract the corresponding allowance for two tides.

Examples.

Required the time of high water at Botany Bay, in Long. 151° 23′ E. on the 21st September, 1825; the time of high water at full and change being 8 h. 0 m.?

The moon's age at Botany Bay, noon, Sept. 21, 1825, is by the last problem, 8 d. 13 h. 55 m.

Corresponding correction for 8d. 13h. 55m. in table, p. 192, ...	6h.	26m.
Time of high water at full and change, . .	8	0
	14	26
Allowance for preceding tide, . . .	12	35
Time of high water, ...	2	51

Hence the time of high water at Botany Bay, on the 21st September, is 51 m. past 2 o'clock P.M.

Required the time of high water at Belfast, July 10, 1848.

The moon's age for the given day at Belfast is, by Prob. II. 9 d. 1 h. 8 m.

Correction for 9d. 1h. 8m. by the table in page 192, is	7h.	2m.
High water at full and change, . . .	10	0
	17	2
Allowance for preceding tide . . .	12	39
Time of high water	4	23

Hence the time of high water is 23 m. past 4 P.M.

Prob. IV.—*Given the whole extent of the flowings at a particular place, to find the height above low water at a given time of the tide.*

Multiply the whole extent of the flowings for high water, by the square of the natural cosine of the horary angle, reckoned from the time of high water, and the product will be the height of the tides nearly. The necessary calculations will be greatly simplified by the following table, in which the flowings are computed for intervals of half an hour, reckoned from the time of high water. The heights of the tides are given for every 10 feet, but the heights for the intermediate units are easily obtained, by removing the decimal point one place towards the left hand.

Total flowing above the level of low water.	Time from high water in hours and half hours.									
	½	1	1½	2	2½	3	3½	4	4½	5
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
10	9.8	9.3	8.5	7.5	6.3	5.0	3.7	2.5	.15	.07
20	19.7	18.7	17.1	15.0	12.6	10.0	7.4	5.0	.29	.13
30	29.5	28.0	25.6	22.5	18.9	15.0	11.1	7.5	44	.20
40	39.3	37.3	34.2	30.0	25.2	20.0	14.8	10.0	.58	.27
50	49.2	46.6	42.7	37.5	31.4	25.0	18.5	12.5	.73	.33
60	59.0	56.0	51.2	45.0	37.7	30.0	22.3	15.0	.88	.40
70	68.8	65.3	59.8	52.5	44.0	35.0	26.0	17.5	1.02	.47
80	78.6	74.6	68.3	60.0	50.3	40.0	29.7	20.0	1.17	.54
90	88.5	84.0	76.9	67.5	56.6	45.0	33.4	22.5	1.31	.60

Examples. At a place where the tide rises on a particular day 48 feet above the level of low water, what is the height of the tide an hour and a half before high water.

	Feet.
Opposite 40 feet, and under 1½ hours, stands .	34.2
Proportional part for 8 feet . . .	6.8
Height of the tide	41.0

What is the height of the tide 2 hours after high water, at a place where the tide flows on a particular day 25 feet?

	Feet.
Opposite 20 feet, and under 2 hours, stands	15
Prop. part for 5 feet . . .	3.75
	Ft. In.
Height of the tide . . .	18.75=18.9

The depth of water laid down on sea charts having a reference to low water, this problem will often be of great use for determining the state of the tide at a place, where the extent of the flowings, and the time of high water are known. It appears by the table, that the difference between the height of the tide at high water, and an hour before or after that event, is very inconsiderable, —a circumstance which fortunately renders it less necessary to calculate the time of high water with a very scrupulous exactness.

CHAP. VI.

Of the great Currents in the Ocean.

A knowledge of the horizontal motion of the waters of the ocean, denominated currents, is scarcely less important to the navigator than that of the diurnal alternations of depth to which they are liable by the flux and reflux of the tides. In some respects, information with regard to the former is even more essential to his safety than a knowledge of the latter; an acquaintance with the state of the tides being only useful in sailing along a coast, or entering a harbour, whereas a knowledge of the setting and drift of currents is necessary for the daily determination of a ship's place, from the beginning to the end of her voyage.

The currents of the ocean, though exceedingly diversified both in velocity and direction, appear to result from the operation of two great causes, the rotation of the earth on its axis, and the inequality of temperature. To these may be added the attractive influence of the sun and moon, which, by continually disturbing the equilibrium of the waters of the ocean, gives rise daily to a great variety of partial currents, which can only be thoroughly explained by an attentive examination of the local circumstances by which they are modified.

By the daily rotation of the earth on its axis, the equatorial parts of the globe are carried from west to east at the rate of upwards of a thousand miles per hour. The waters of the ocean are not allowed to partake of the whole of this velocity, on account of their mobility, and the attraction of the two great luminaries, which incessantly acting on their particles, prevents them from acquiring that stable condition of revolution, which they must otherwise have ultimately attained. Hence the solid parts of the globe being carried faster to the eastward than the waters of the ocean, the latter appear to have a motion in a contrary direction; and by this is produced that great equatorial current from east to west, which is known to prevail in the tropical regions.

The other cause, the inequality of temperature, gives rise to a current from the poles towards the equatorial parts, though its effects are neither so unequivocal, nor so extensively developed. The superior temperature of the atmosphere within the tropical zone, causes a much greater quantity of water to be evaporated from the surface of the ocean in that quarter than is subsequently restored by the rains, and the discharge of rivers. By the atmospherical currents, which we shall afterwards consider, the water thus evaporated is incessantly transported towards both poles. During its progress, however, in these opposite directions, it is gradually exposed to a temperature more and more reduced, by which it is slowly converted to the state of water; and, descending in the form of rain, supplies the various zones at a distance from the equator, with a greater quantity of moisture than they lose by evaporation. By this means the polar and temperate zones being furnished with a larger supply of water than is consistent with that form which the earth should possess, by the joint action of gravity and the centrifugal force of revolution, a current of the superfluous water must take place from the poles to the equator. This current, from the small quantity of water by which it is determined, is not very perceptible in the open ocean, but its actual existence is demonstrated by the floating masses of ice which are annually transported from each of the frigid zones towards the tropical regions.

The great equatorial current which we have already alluded to, has even been ascribed entirely to the same cause. The waters flowing from the colder zones, to supply the quantity carried off by evaporation within the tropics, coming from regions where they were endowed with a smaller velocity of rotation, cannot, it must be admitted, suddenly acquire the same velocity as the more solid parts of the globe at the equator; and hence, like the great aerial fluid by which it is surrounded, they must appear to have a slow motion from east to west. That the equatorial current is partly owing to this, is very probable; but it seems too much to ascribe it entirely to a cause so apparently inadequate.

In endeavouring to trace the directions of the subordinate currents, produced by the equatorial and polar streams, we shall begin at the western coast of America, both because the outline which it forms is the largest in one direction, which marks the boundary of land and water on the surface of the globe, and because, being nearly at right angles to the principal current, it seems, on that account, a better line of reference than any other. The Pacific Ocean, extending with little interruption to the westward of this line, the equatorial current from east to west appears to prevail almost universally over this vast expanse of water. Having reached, in its motion round the globe, the eastern coasts of Asia and New Holland, its direction is considerably modified by the various obstacles which suddenly oppose its progress to the Indian Ocean. One portion of the water forcing its way round the southern point of New Holland, occasions the strong currents which have been experienced by navigators in the straits between that island and Van Diemen's Land; while another portion of it, escaping through the various winding channels, formed by the clustered islands situate between the northern extremity of New Holland and the coasts of Asia, produces a great variety of subordinate currents, whose directions are affected by local circumstances, a particular detail of which it is unnecessary to enter upon. After entering the Indian Ocean, the equatorial current, influenced probably by the polar current from the south, takes a north-westerly course, and proceeds towards the Gulf of Bengal. Having doubled Cape Comorin, it advances to the coasts of Africa, and sweeping along the shores of that continent with augmented velocity, it again joins the general current in the Southern Atlantic, and resumes its westerly course.

In the Atlantic Ocean, the effects of the equatorial current are distinctly recognised between the tropics: and within that range prevail, with very little exception, from the western coast of Africa to the eastern shores of America. On reaching the coast of Brazil, it diverges at Cape St. Augustine into two streams, one of which, proceeding in a south-west direction, runs parallel to the coast till it falls into the Pacific beyond Cape Horn; the other, following a north-westerly course, enters the Caribbean Sea, and afterwards penetrates into the Gulf of Mexico, between Yucatan and the island of Cuba. The former of these branches being resisted by the polar current from the south, occasions several opposite currents between Sandwich Land and the island of Terra del Fuego.

The other branch, which enters the Gulf of Mexico, conspires with the large rivers that pour themselves into it, to raise the waters of the ocean considerably above their natural level along the shores which oppose their progress to the westward, in consequence of which they are forced to escape, with increased velocity, between Florida and Cuba. This powerful current, so well known to seamen under the name of the *Gulf Stream*, is afterwards compelled to flow towards the north-east, by the direction of the American coast. In its progress to a colder climate, it is distinguished from the waters of the Northern Atlantic, by its superior temperature, and beautiful blue colour. Its influence is even felt as far to the northward as Newfoundland, where it produces, by the copious exhalations from its surface, the dense fogs which generally hang over the surface of that inhospitable island. After reaching Newfoundland, however, it becomes more exposed to the effects of the polar current from the north, by which its direction is determined more and more towards the east, and, aided by the westerly winds which prevail in that latitude, it shoots across the Atlantic to the coasts of Norway and the British isles. Here it is constrained, by the superior influence of the polar current, to assume a direction more southerly, and, after advancing along the western shores of Europe and Africa, to join the great equatorial stream, probably a little beyond the Cape Verd Islands.

Contiguous currents, flowing in opposite directions at the surface, are far from being of rare occurrence. Thus in the Cattegate, it is well known that one current enters the Baltic along the coasts of Jutland, while another glides out of it by the opposite shores of Sweden. In like manner, a current seems to proceed along the eastern coast of Britain towards the south, while another, flowing in an opposite direction, advances along the coast of Holland. The existence of opposite currents at different depths, though less frequent, is established by observation. Even in some parts of the Caribbean Sea, where the equatorial current is strongly felt, it is affirmed a boat may be retained in a fixed position, by suspending from it a heavy body, at a depth sufficient to place it beyond the influence of the superficial stream. The stability of the boat, in such circumstances, must be ascribed to the operation of a contrary current below, which tends to carry the immersed body in an opposite direction to that in which the boat would be carried by the sole action of the stream at the surface. The eddies, formed by ledges of rocks, running transversely to the direction of the stream, afford a sufficient explanation of the cause of these opposite currents at different depths.

The usual method of determining the setting and drift of a current, is, on account of what has just been stated, liable to much uncertainty. A boat being commonly employed for the purpose, is rowed, during a calm, to a small distance from the ship, where she is brought up, by sinking with a sufficient length of line some heavy object, as a pot, to a depth where it is supposed to be beyond the influence of superficial currents. The log being then hove, the number of knots run out in half a minute gives the drift, while the bearing of the log itself determines the setting of the current.

In estimating the direction and velocity of currents, on the large scale, the practice among seamen is, to lay down the position of the ship, as inferred from dead reckoning, and to compare it on the chart with her place as deduced by celestial observation; but in following out this method during a long voyage, the ship's tract, in each of these cases, soon assumes a very different appearance, so that the influence of a current which may have affected the ship's course, made good at any particular time, cannot be detected without a good deal of trouble. To obviate this inconvenience, it has been proposed by Captain Basil Hall, to take on all occasions when the ship's place has been determined accurately by celestial observation, a fresh departure, and to draw from the point on the chart, marking the ship's position, two lines, one to the next true place, and the other to the place by dead reckoning, at the same time. By adopting this plan, the true tract of the ship, as indicated by the course and distance made good between the celestial observations, would form a series of continuous lines; whereas the several distances made good by dead reckoning would be a number of detached lines, each running off from the respective true place of the ship to which it had a more immediate reference. The principal advantage derived from this mode of procedure is, that the line joining the ship's place by celestial observation, and her place by dead reckoning, will always indicate both the setting and drift of the current, for the interval of time between consecutive observations. See *Edin. Phil. Journal*, vol. ii. p. 277.

The only objection of any weight that may be urged against this method of finding the direction and velocity of currents is, that it proceeds on two suppositions, neither of which is strictly true: namely, that the data from which the ship's place is determined, whether by observation or dead reckoning, are in both cases perfectly correct. It is scarcely necessary to observe, that the course given by the compass, after every allowance has been made upon it for variation, leeway, and local attraction, must, from the imperfect nature of the instrument, be often wide of the truth; while the ship's run, on account of the errors to which it is liable from the mode of estimating it by the log, must be considered at best as only an approximation to the actual distance. On the other hand, the errors inseparable from celestial observations for finding the longitude, even when they are made by the most experienced practitioners, are certainly beyond the limits of that degree of precision that would seem to be required, for determining a ship's true place with sufficient accuracy to ascertain the drift of a current, for so short an interval of time as that in which nautical observations are usually made. These objections, indeed, so far as the ship's place by celestial observations is concerned, may be got over by the use of a chronometer, which, if it goes with tolerable accuracy, cannot deviate far from true time, in the course of twenty-four hours; but they apply with equal force to the place assigned by dead reckoning; and, in the present case, an error in the one is no less liable to mislead than in the other. On the whole, however, the above method of ascertaining the setting and drift of currents, when every precaution is used to guard against the sources of error we have noticed, is perhaps the only one that can be employed, with success, for finding the direction and velocity of the more extensive currents which prevail in different places of the ocean.

CHAP. VII.

Of Winds.

Winds being the grand agents by which a ship is impelled across the ocean, as well as seas of more limited extent, some knowledge of their general characters cannot fail to be highly useful to the seaman. As they are aerial currents, set in motion by the same causes which give rise to currents in the ocean, they will be found to possess, in many respects, a considerable resemblance to the latter. In designating their direction, however, a method is adopted the very reverse of that which is applied to the currents of the ocean; as they are described, not by their setting, but by the name of the quarter of the horizon from which they proceed.

Winds are naturally distinguished into *constant* and *variable*. The former, which are better known by the name of *trade winds*, prevail, with little exception, between the tropics, and, like the great equatorial current of the ocean, circulate round the globe from east to west; the latter are to be found on the north of the tropic of Cancer, and the south of the tropic of Capricorn, though their limits with respect to these circles are not always the same in either hemisphere.

The trade winds extend to about 30° on each side of the equator, and blow with a steady breeze almost the whole year from east to west. Their direction, however, declines a little from due east, toward the parallel to which the sun is vertical at different seasons of the year, being a little northerly when the sun's declination is north, and a little southerly when it is of an opposite denomination. The cause of this wind, so remarkable on account of its uniformity, is principally owing to the joint influence of the superior temperature of the torrid zone, and the rotation of the earth on its axis. By the former condition, the air at the surface of the earth within the tropics being greatly rarified, ascends by its acquired levity into the higher regions of the atmosphere. Its place is supplied by the colder air rushing from the poles towards the equator, which, being also rarefied, ascends in its turn, and is ultimately carried towards the two poles to supply the stream from these points. An aerial current is thus established, proceeding from the poles towards the equator in the lower regions. Each of these polar currents moving in its progress towards the equator, from zones where the earth's motion on its axis is slower, to others where it is more rapid, cannot have the same velocity eastward as the solid parts of the globe; and therefore the aerial particles of which it is composed gradually acquire a relative motion in an opposite direction. The currents from the two hemispheres meeting near the equator, and verging each of them towards the west, their meridional motions are destroyed by being in opposite directions, and they therefore advance together with the remaining motion from the eastward all round the globe.

The regularity of the trade wind is, in some places, disturbed by the operations of certain causes of a local description, which it is not easy to explain. As the sun advances towards the tropic of Cancer, the trade wind becomes less steady over the whole of the Indian Ocean, and in certain situations is succeeded by a wind blowing in an opposite direction, which continues with great regularity for several months. These periodical winds, which have received the appellation of *Monsoons*, have been ascribed to the superior temperature acquired by the southern part of the African and Asiatic continent during the time the sun is vertical to it, in consequence of which an aerial current takes place from the sea towards the land. The following facts, for which we are chiefly indebted to the celebrated Dr. Halley, comprise almost all that is known respecting these winds.

In that portion of the Indian Ocean lying between Sumatra and the African coast, and from 3° of south latitude to the Asiatic coast, including the Arabian Sea and the Gulf of Bengal, the monsoons blow from September to April north-east, or nearly in the general direction of the trade wind; but from April to September they change to the south-west, and more in with the land to the west south-west. During the former period it is remarked that the wind is more steady, and the weather less liable to sudden changes.

Another of these monsoons is observed to take place between the island of Madagascar and the coast of Ajan, north of the equator. In that tract of sea, from April to October, the wind blows with a steady breeze about S.S.W. but from October to April it resumes the general direction of the trade wind, and varies from N. E. to E. N. E.

A monsoon of a less determined character occurs in the Chinese seas, extending from Sumatra to Japan. The periodical winds in this tract seem to be greatly influenced by the large islands which bound it on the south, particularly Java, Borneo, and perhaps we may add, New Holland. Their prevailing directions from October to May is from north to south, inclining a little westward.

When a change is about to take place in the direction of the monsoons, it is usually preceded by calms and variable winds. In some cases, particularly along the Coromandel coast, and the shores of China, the transition is accompanied with violent gales, resembling the hurricanes in the West Indies, and which are no less fatal to vessels, unfortunately exposed at that time to their destructive effects.

Having thus taken a general view of the modifications produced on the trade wind in the Indian seas, by circumstances of a local description, we shall briefly consider the effects of similar causes on this great aerial current, in its passage across the Atlantic Ocean. We have already stated, that the general direction of the trade wind is from east to west. This is found to hold true within the tropics in the Atlantic Ocean, at the distance of about 300 miles from the African coast; but from Sierra Leone to the island of St. Thomas, the trade wind yields to southerly and south-westerly breezes which prevail there the whole year with little interruption. A little more to the northward, from the latitude of 4° to 10° north, in consequence of the general trade wind in that quarter being counteracted by the breezes towards the African shores, there is a pretty extensive tract of the ocean which is subject to perpetual calms, attended with dreadful thunder storms, and almost incessant rains. The portion of the Atlantic which is known by the name of the *Rains*, extend in breadth from the longitude of Cape Verd to the longitude of the eastermost of the Cape Verd islands, and is carefully avoided by vessels trading to the coast of Guinea, on account of the danger and delay to which it at once exposes them.

On the American coast the trade wind reigns with scarcely any control. Hence its influence is felt in both hemispheres at a greater distance from the equator on the western, than on the eastern side of the Atlantic; for whereas this regular wind extends on the African side only as far as 28°, on the American side it is experienced as high as the latitude of 32°.

In the great Pacific Ocean the trade wind blows with an uniform gentle breeze during the whole year. Spanish vessels trading between the western coast of South America and the Manilla islands, are said to traverse this vast ocean in ten weeks without having once occasion to alter a sail; and accordingly it is supposed, that ships sailing from Europe might reach the Chinese seas in as short a time by doubling the southern promontory of America, as by proceeding round the Cape of Good Hope.

The variable winds possess no character in common, except that of irregularity. They commence at no stated periods, and blow at the same season with various degrees of intensity, and in the most opposite directions. At the same time, they are not so utterly anomalous as to be altogether destitute of certain distinguishing peculiarities in different places. Thus, in both hemispheres, a little beyond the limits of the trade wind, a westerly wind prevails more frequently than any other; and hence ships sailing to the eastward always endeavour to reach the parallel of 34° or 35° before they attempt to alter their longitude. In higher latitudes the variable winds become more and more irregular; but even over the whole of the temperate zones, it may be said of them that they blow more rarely from the east than the west side of the meridian.

From the general facts we have stated, it is easy to perceive a very striking analogy between the prevailing currents of the ocean and those of the atmosphere. Both are produced by the operation of the same causes, and both seem to be modified nearly in the same manner by the influence of local circumstances. It is even highly probable that they have a mutual influence on each other, though it would be advancing too much to affirm, that the great equatorial current of the ocean has arisen entirely from the ceaseless operation of the trade wind.

The velocity of the wind varies, in every possible degree, from the gentle motion of the breeze that is barely perceptible, to the overwhelming blast of the hurricane which sweeps every thing before it. According to the experiments of Mr. Rouse, published by Smeaton in the 51st volume of the *Transactions of the Royal Society of London*, a gentle light breeze moving with a velocity of about five miles an hour, presses on a surface of a square foot, placed at right angles to its direction, with a force of nearly two ounces avoirdupois; a pleasant brisk gale, having a velocity of 10 to 15 miles an hour, with a force of from half a pound to double that quantity; a high wind, sweeping with a velocity of 50 miles an hour, with a force of upwards of 12 pounds; and a hurricane having the enormous velocity of 100 miles an hour, that tears up trees, and overturns houses, with a force of about 49 pounds. It may be concluded from these facts, as well as from theory, that the force of the wind must be nearly in the duplicate ratio of its velocity; and hence the reason why a gale, when it reaches a certain pitch of intensity, has its violence greatly augmented by a comparatively small increase of its velocity. Thus a gale having a velocity of 60 miles an hour, would press against any obstacle opposed to it with more than double the force of one which has only a velocity of forty miles an hour.

When the direction of the wind is oblique to the surface against which it impinges, the force with which it strikes against it is less than that of its direct impulse, in the proportion of the square of the radius to the square of the natural sine of the angle of obliquity. Thus the natural sine of 30° being .5 when the radius is unity, a sail which would be impressed with a force of one pound on every square foot, when the wind struck it at right angles, would only be exposed to a pressure of a quarter of a pound on every square foot, when braced to an angle of 30° to the direction of the wind; the square of .5 being .25 or equal to the fraction $\frac{1}{4}$.

When a ship sails before the wind, that is, with the wind right a-stern, the effect of the moving fluid is proportional, not to its velocity, but to the square of the difference of the velocity of the wind and that of the ship. Thus if two ships, whose rates of sailing were, in similar circumstances, as 3 to 4, should both sail before the wind, the one moving 9 knots, and the other 12, while the absolute velocity of the wind was 35 miles an hour, the effect of the wind on the two ships would be very different; for, whereas the former would be impelled with a force proportional to the square of the difference of 35 and 9; that is, the square of 26 or 676, the latter would be impelled only with a force proportional to the square of the difference of 35 and 12, that is, the square of 23 or 529. Hence the effect of the wind on the two ships would be nearly as 9 to 7, so that the heavy sailer might nearly keep up with the other, though she would soon be left far behind if she sailed with her on a wind.

Sudden and violent gales of wind, having their immediate cause in some rapid diminution of the pressure of the air in the vicinity of the quarter where they take place, are invariably accompanied or preceded by a sinking of the mercury in the barometer; and hence this instrument never fails to indicate, particularly within the tropical regions, the approach of a storm. The best form of the instrument for marine purposes, is that of the sympiesometer, invented by Mr. Adie, the great value of which, it may be hoped, will soon bring it into general use. See BAROMETER, METEOROLOGY, and SYMPIESOMETER.

CHAP. VIII.

Of the Methods of determining geographical Positions by means of physical Relations.

Though we have allotted an entire chapter to this branch of geographical navigation, it is rather with the view of exciting attention to the subject, than from the hopes of being able to communicate much useful or satisfactory information respecting it. It is only of late, indeed, that what may be called the physiology of the globe has been studied with that minuteness of observation, and at the same time comprehensiveness of inquiry, which are necessary to establish general relations; and though many important facts have been brought to light by the industry of intelligent and well-informed voyagers, much still remains to be done before we can acquire that accurate knowledge of the physical condition of the various zones, which is necessary to mark with precision their geographical position.

In the concise view which we mean to take of the subject, we shall first consider the methods of a more general application, by which a ship's place may be inferred from the temperature of the ocean; and secondly, the indications which, in certain cases, announce the vicinity of land.

The determination of a ship's place in general, by means of the temperature of the ocean, admits of little precision, and is only to be resorted to when every other method has left us in uncertainty. The thermometer, the instrument to be used for obtaining the necessary data, should be of the most delicate construction; and the graduation of it should extend at least to half degrees. The water whose temperature is to be examined, for the purpose of finding either the latitude or the longitude, should be taken from a depth at which it may be supposed to possess a temperature peculiar to its geographical situation. When it is taken too near the surface, it is liable to be affected by temporary changes in the atmospheric temperature; and, on the other hand, when it is brought up from too great a depth, it may have been beyond the influence of those superficial communications of heat, by means of which the temperature of each zone acquires a certain condition, which has, within assignable limits, a pretty constant relation to the latitude. The effects of winds and currents may render it necessary to take the water from various depths, in different situations; but in general, it may be recommended to bring it up from the depth of about 5 fathoms. The moment the water is got on board, it should be examined by plunging the thermometer into it, and the instrument, after being gently moved backwards and forwards for the space of a minute, should be observed, without removing the bulb from the water. The temperature of the water being thus obtained, it remains to deduce from it the latitude, and in certain cases the longitude. Here, however, it is exceedingly difficult to give rules of general application: for though the ocean is by no means liable to the sudden changes to which the air, by its more perfect mobility, is exposed, its temperature varies in each latitude, with the sun's declination, and observations are yet wanting to establish the limits within which it ranges, as well as the rate of its periodical increase and diminution. Instead, therefore, of attempting to give a general rule for deducing the latitude from the temperature, we shall subjoin a table of the temperature of a considerable number of positions in each hemisphere, with the authorities on which they rest.

Table of Temperature of the Seas in both Hemispheres.

Latitude.	Longitude.	Period of the observation.	Temp. of the ocean at its surface.	Oceans.	Names of the observer.
3° 53′ N.	90° 26′ W.	Feb. 1803	83°.6	South Sea.	Humbt.
3 16 S.	86 23 W.	Jan. 1803	80.6		Idem.
4 8 N.	22 54 W.	Oct. 1788	81.5	Atlantic.	Churruca
3 44 S	28 10 W	Nov. 1788	80.6		Idem.
4 36 N.	53 50 E	May 1800	81.7	Ind. Sea.	Perrins.
4 44 S.	24 51 W	April 1800	79.5	Atlantic.	Idem.
11 12 N.	37 34 W	April 1800	80.8	Do.	Quevedo
11 32 S.	29 41 W	March 1803	80.6	Do.	Idem.
11 58 N	25 46 W	March 1800	73.8	Do.	Perrins.
12 30 S.	27 20 W	April 1800	78.4	Do.	Idem.
15 24 N	39 44 W	April 1803	74.8	Do.	Quevedo
15 50 S	30 34 W	March 1803	79.9	Do.	Idem.
23 0 N	26 50 W.	March 1800	69.8	Do.	Perrins.
23 40 N.	41 6 W.	April 1803	71.8	Do.	Quevedo
22 52 N.	22 13 W.	June 1799	68.0	Do.	Humbt.
23 23 S.	28 58 W	March 1803	*80.6	Do.	Quevedo
23 28 S.	29 40 W.	April 1800	75.9	Do.	Perrins.
23 30 S.	50 10 E	May 1800	71.6	Ind. Sea.	Idem.
31 6 N.	79 37 W.	May 1804	70.7	Atlantic.	Humbt.
31 22 N	15 7 W.	Oct. 1788	74.5	Do.	Churruca
31 58 N.	20 10 W.	March 1800	63.9	Do.	Perrins.
31 30 N.	38 45 W.	April 1803	69.3	Do.	Quevedo
31 34 S.	28 29 W.	March 1803	75.7	Do.	Idem.
31 0 S.	26 20 W.	April 1800	68.9	Do.	Perrins.
31 34 S.	46 56 W.	Nov. 1788	68.9	Do.	Churruca
31 4 S	47 40 E.	May 1800	66.9	Ind. Sea.	Perrins.
36 38 N.	41 2 W.	May 1803	66.7	Atlantic.	Quevedo
36 5 N	76 41 W.	May 1803	68.0	Do.	Humbt.
36 4 N.	17 5 W.	June 1799	59.4	Do.	Idem.
33 16 N.	10 24 W.	Oct. 1788	72.3	Do.	Churruca
35 22 S.	50 32 W.	Nov. 1788	63.0	Do.	Idem.
36 3 S	17 8 W.	April 1800	65.8	Do.	Perrins.
36 5 S.	41 58 W.	May 1803	68.0	Do.	Quevedo
33 52 S.	94 52 W.	Feb. 1803	71.6	South Sea.	Idem.
40 28 N	33 35 W.	May 1803	62.8	Atlantic.	Idem.
40 30 N.	68 36 W.	July 1804	65.7	Do.	Humbt.
42 34 N.	15 45 W.	Feb. 1800	57.6	Do.	Perrins.
42 30 S.	50 30 W.	March 1803	55.8	Do.	Quevedo
40 36 S.	48 20 W.	March 1803	59.9	Do.	Idem.
40 48 S.	93 56 W.	Feb. 1803	62.6	South Sea.	Idem.

The above table is taken from Humboldt's *Personal Narrative of Travels in the Equinoctial Regions.* The temperature of the waters under the same parallel, appears to differ considerably at different seasons of the year; but it is very probable that if, in place of being taken at the surface, the water had been brought up from the depth of 10 or 12 fathoms, it would have possessed a temperature more characteristic of its geographical situation, and more nearly coinciding with the mean temperature of the parallel. From the formula for the mean temperature of a place, suggested by Dr. Brewster, viz. T=81.5 cos. lat.† in which T. denotes the mean temperature, according to Fahrenheit's scale, we might have the following analogy for finding the latitude. As 81.5 is to the temp. in deg. of Fahr. so is radius to cos. latitude.‡

It is proper to state, however, that a slight inaccuracy in the observation of the temperature, would lead to a considerable error in the calculation of the latitude, by means of it; and, in short, that little reliance could be placed upon the result, unless it were confirmed by other methods.

The determination of the longitude by the temperature of the ocean is, in some cases, attended with less uncertainty. The great currents of the ocean, which tend so much to disturb the temperature belonging to the different zones, by urging along certain coasts, streams at a more elevated temperature than that of the adjacent seas, afford the means, particularly when they run north and south, of fixing the longitude of a given parallel with a good deal of precision. Thus the gulf stream of Florida, setting along the American coast, and retaining, as far north as the parallel of 45°, a temperature which is frequently more than 10° higher than the temperature of the Atlantic, on either side of the stream, forms a kind of physical barrier, which cannot be crossed without being discovered by the most careless observations; and hence, after a long voyage from Europe, it enables the mariner to rectify his longitude, at the very time when he has most occasion to know it with accuracy. The truth of these remarks will be best perceived by the following extracts from the log book of the Phebe, of Kincardine, communicated by captain Anderson, to the writer of this article.

First Voyage§ approaching Charleston.

Period.	Latitude.	Longitude.	Temp. Water.	Temp. Air.	
1819.					
Mar. 19.	32° 41′	76° 52′	68	70	
…… 20.	32 53	77 52	63	60	
…… 21.	33 29	78 57	74	50	Gulf stream.
…… 22.	32 48	80 46	64	60	

Second Voyage approaching Charleston.

Period.	Latitude.	Longitude.	Temp. Water.	Temp. Air.	
1819.	N.	W.			
Oct. 26	30° 49′ N.	75° 11′ W.	72	72	
…… 27.	31 34 N.	76 47 W.	74	72	
…… 28.	32 44 N	77 41 W.	77	72	Gulf stream.

Same Voyage leaving Charleston.

Period.	Latitude.	Longitude.	Temp. Water.	Temp. Air.	
1820.					
Jan. 20.	32° 18′ N	79° 1′ W.	66	59	
…… 21.	32 23 N.	77 55 W.	73	61	Gulf stream.
…… 22.	33 6 N.	76 37 W.	72	72	
…… 23.	33 24 N.	74 40 W.	66	68	
…… 24.	33 35 N.	71 33 W.	64	64	

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* Apparently too great.

† This formula is suited only to the west of Europe.

‡ In a subsequent paper, he has shown that the *Isothermal lines,* or lines of equal temperature, are related to two poles of greatest cold, one on each side of the real pole. See *Edinb. Phil. Trans.* vol. ix.

§ The longitude was deduced, either directly or indirectly, from lunar observations.

It appears by these extracts, that the limits of the gulf stream are more distinctly observed when the sun is in the southern, than in the northern hemisphere. This is evidently owing to the temperature of the general mass of waters in the Northern Atlantic, being higher in the latter case than in the former. At all seasons, however, the difference is such as to afford a sure indication of a transition from the contiguous ocean to the stream, with this important advantage, that the necessary observations can easily be made in all states of the weather, and at every hour of the day. With a good observation of the latitude, the longitude may be inferred by the indications of the thermometer, generally within half a degree.

The use of the thermometer for announcing the vicinity of land, sand banks, shoals, &c. has been established beyond all doubt. At very great depths, the temperature of the ocean, even within the tropical regions, is found to be greatly below its temperature at the surface; and the rate of diminution is observed to be more rapid over shoals, and in the vicinity of land, than in the open ocean. It has been ascertained, that even at the surface, a considerable diminution of the temperature of the sea takes place on approaching a shoal, in so much, that the proximity of land may always be discovered with great certainty by the sudden descent of the thermometer. Humboldt mentions, that in crossing from Corunna to Ferrol, the temperature of the water at the surface varied from 54.3 to 59.5, according as the observations were made in shallow or deep water; and Mr. Livingston, in the *Edinburgh Phil. Journal*, vol. iii. p. 247, describes several instances, in which similar variations were noticed, both on the European and American coasts.

But the thermometer, however valuable for indicating the approach of shoals, ought never to supersede the more direct method of ascertaining the same thing by *sounding*. This operation, so familiar to every practical seaman, consists in determining the depth of the water, and the quality of the bottom, in any situation, by means of a heavy piece of lead, of a proper form, and a line of sufficient length. The lead, which is of different weights, according to the depth of water, is furnished with a cavity at the lower end, in which is occasionally fixed a piece of hog's lard or tallow, for the purpose of determining the nature of the bottom. The shells, sand, &c. at the bottom, by adhering to the tallow, are brought up with the lead, and thus frequently serve to indicate a ship's position, on a known coast, particularly when they are taken in connection with the soundings or depth.

PART II. ASTRONOMICAL NAVIGATION, OR NAUTICAL ASTRONOMY.

THE imperfect nature of the instruments by which a ship's course and distance are estimated, together with the unavoidable errors arising from an improper allowance for magnetic variation, the heave of the sea, leeway, and unknown currents, frequently render the geographical position inferred from dead reckoning to differ widely from the truth. Hence, it is to the mariner a matter of the utmost importance to be able to verify his reckoning, from time to time, by celestial observation, and to deduce from the altitudes, and angular distances of the heavenly bodies, his true latitude and longitude.

Before commencing the study of this branch of navigation, the reader must be familiarly acquainted with the positions and relations of the various imaginary lines to which astronomers refer the places of celestial objects; and he would do well to peruse with care sect. iii. art. vi. ASTRONOMY; and GEOGRAPHY, chap. i. sect. ii.

CHAP. I.

Of the Instruments necessary in Nautical Astronomy.

THE quantities to be determined by observation being the intercepted arches of great circles of the celestial sphere, the only instruments requisite in nautical astronomy, besides a good chronometer, are such as can be employed with advantage for the measurement of angular distance. Hence the circle itself, or some portion of it duly graduated, constitutes the basis of all the instruments used in nautical astronomy, except the watch, or chronometer. The principle of reflection from two plane mirrors, first employed in the construction of the nautical quadrant by Hadley, is still used, both in the circle, and the various sectors of it; and it must be allowed, that no contrivance could have been adopted that is more simple, or better calculated to answer the proposed end.

Under reflecting instruments used at sea, are reckoned, 1st, The *Octant*, or, as it is sometimes called, the *Quadrant*; 2d, The *Sextant*; and 3d, The *Circle*. The great value of these instruments has induced us to give a very particular account of their construction and uses, under their respective names; and we must, therefore, refer to CIRCLE, and to QUADRANT, for an ample account of any thing connected with these valuable and important instruments.

The mariner's compass has been already noticed, under the instruments used in geographical navigation; that form of the instrument which is employed for determining the azimuth of objects, in order to ascertain the magnetic variation, will be described under VARIATION.

The only additional instrument which may occasionally be necessary for the purposes of nautical astronomy, is what is called an *Artificial Horizon*. The design of it is to supply the want of the apparent horizon, when the farthest verge of the ocean is indistinctly perceived, by the haziness of the lower regions of the atmosphere,—a circumstance which occurs not unfrequently at sea, even when objects at the height of 10° or 15° are clearly discerned, and well defined.

The simplest, and perhaps the best contrivance that has yet been recommended for procuring an artificial horizon, is to pour into a circular vessel of wood or glass, about three inches in diameter, as much mercury as will cover the bottom of it, to the depth of about $\frac{1}{4}$ of an inch, and then to suspend it in jimbals, in order to counteract, as far as possible, the tremulous motion produced on the surface of the mercury by the agitation of the ship. To screen the fluid from the wind, the vessel which contains it should have a covering of glass; but to guard against the errors arising from refraction, the two sides of the glass should be exactly parallel. Perhaps it would answer the purpose still better, to have the glass cover to rest on the surface of the mercury, the diameter of the glass being such as to allow it just to play freely within the vessel containing the mercury. This would not only shelter the mercury from the wind, but obviate the effects that might be produced by the concave surface of the metal. When mercury cannot be procured, tar, treacle, or some dark-coloured oil, of a viscid consistency, may be substituted in its place.

A top, having a plain mirror at right angles to its axis, when it is spun with great velocity, is observed to afford, after it has been two minutes in motion, a very steady horizon. A contrivance for procuring an artificial horizon, on this principle, was accordingly recommended, about the middle of the last century, by Mr. Serson; but though it answered extremely well on land, it was found to be subject to so great irregularities at sea, that the use of it was soon abandoned. This instrument, however, has lately been revived by Mr. Troughton, whose ingenuity has done much to remove the imperfections to which it was subject, though it is to be feared that even this scientific artist will scarcely be able to give it that steadiness of horizontality which is necessary for observations on board of a ship. See *Edin Phil. Journ.* vol. i. p. 105.

Whatever contrivance is used for obtaining an artificial horizon, the image of the object in the sextant should be brought in contact with its image on the surface of the mercury, &c. or speculum of the top. Then half the angle on the instrument will be the apparent altitude of the object's lower limb, without requiring any correction for dip.

CHAP. 7. 6

Of the Corrections to be applied to the Quantities used in Nautical Astronomy, to prepare them for subsequent Calculation.

The quantities employed in nautical astronomy for deducing a ship's place by celestial observation, are obtained either by the actual measurement, with appropriate instruments, of the arches of certain great circles; or by means of tables, previously computed from established principles, in which the necessary elements are laid down for such intervals of time as the changes which they undergo may require. Both these quantities, however, must receive various corrections; the former, that they may be divested of the local and accidental peculiarities under which they were observed; and the latter, to adapt them to the actual circumstances of the case to which they are to be applied.

SECT. I.—*Of the Corrections to be applied to Quantities obtained by Actual Observation.*

1. *Of the Dip, or Depression of the Horizon.*

The altitude of a heavenly object, as it is obtained by observation, being an arch of a vertical circle, intercepted between the object and the apparent horizon, it is evident that this arch must be greater as the eye of the observer is raised above the plane of the horizon. Let A be any place at the surface of the earth, *b* AB the sensible horizon of that place, A′ a point directly vertical to A, and *b*′ A′B′ the corresponding horizontal plane; then C being the centre of the earth, if O be an object at a great distance, the angle B′A′O will not differ sensibly from the angle BAO, the apparent altitude at A; but at A′ the apparent altitude will not be the angle B′A′O, but the angle OA′E, which differs from the former by the angle B′A′E. This difference, which varies with the altitude of the observer, is called the *Dip* of the horizon, and is equal to the angle at the centre ACE. We shall compute the magnitude of it for a particular altitude in feet, and then give a general expression, by which it may be determined with sufficient accuracy in all other cases.

Let r denote the radius of the earth, corresponding to the mean parallel of 45°, in which case it is 20972190 feet; then, if h be the height of the observer, in feet, above the surface of the ocean, and t the tangent at the point A′.

$$t = \sqrt{\overline{DA'} \times \overline{AA'}} = \sqrt{2\,r\,h + h^2}$$

But if the arch AE, which, from what we have shown, must measure the dip, be represented by D, then, from the well known expression for an arch, in terms of its tangent,

$$D = t - \tfrac{1}{3}t^3 + \tfrac{1}{5}t^5 -, \text{\&c.}$$

If t be expressed in terms of the radius, considered as unity, then h must be divided by 20972190, by which means it will become a very small fraction, and it will be quite unnecessary to retain more than two terms of the above series. We shall thus have $t = \left(2\,h + h^2\right)^{\frac{1}{2}}$, and

$$D = \left(2\,h + h^2\right)^{\frac{1}{2}} + \tfrac{1}{3}\left(2\,h + h^2\right)^{\frac{3}{2}};$$

$$\text{or } D = \left(2\,h + h^2\right)^{\frac{1}{2}} \left\{1 + \frac{2\,h + h^2}{3}\right\}.$$

This expression will give the dip in minutes, if it be multiplied by 3437 75, the number of minutes equal to the radius, when the circumference is 360°; but before it can be used for practical purposes, it must be corrected for atmospherical refraction, one of the corrections which we shall afterwards consider. At present it is sufficient to state, that, according to La Place and De Lambre, the effect of refraction, in the ordinary condition of the atmosphere, is, to increase angles of elevation observed near the surface of the earth, $\frac{8}{100}$ of the intercepted terrestrial arch between the object and the place of the observer. Hence the angle AA′E must be multiplied by $\frac{100}{108}$ to reduce it to its proper magnitude divested of refraction. We thus obtain

$$D = 3437.75 \times \frac{100}{108}\left(2\,h + h^2\right)^{\frac{1}{2}} \left\{1 + \frac{2\,h + h^2}{3}\right\}$$

For elevations not exceeding 400 feet, it will be sufficiently correct to give this expression the form

$$D = 3183\sqrt{2\,h + h^2}, \text{ or even } D = 3183\sqrt{2\,h}.$$

Thus, if $h = 25$ feet, then $h = \dfrac{25}{20972190} = 00000119205.$

$$\text{And } D = 3183\sqrt{\cdot 0000023841} = 3183 \times \cdot 00154 = 4'{\cdot}9.$$

It appears by the approximated expression, $D = 3183\sqrt{2\,h}$, that the dip for different elevations above the level of the sea, is nearly proportional to the square root of the height; and since we have found it 4′.9 for 25 feet, we obtain for any other height in feet H,

$$D = \frac{4\,9}{5}\sqrt{H} = \sqrt{H} \text{ nearly.}$$

Hence the dip in minutes is very nearly equal to the square root of the altitude in feet. This method of finding the dip, the simplest, we believe, that has yet been given, will seldom differ in result above four or five seconds from the most rigid calculation, and, considering the changeable nature of the height of the observer at sea, may be regarded as sufficiently correct for all practical purposes. We deduce from it the following practical rule for the calculation of the dip: Take half the logarithm of the heighth of the eye of the observer in feet, and it will be the logarithm of the dip in minutes.

Example.—What is the dip of the horizon for an observation taken at the height of 45 feet above the surface of the ocean.

Log. 45 = 1.65321
½ of which is ·82660 = Log. of 6.7.
Hence the dip is 6′.7, or 6′.42″.

The dips for the different heights from 1 foot to 300 feet, are found in Table III.

When the proper extent of the horizon is limited by a fog, or intervening land, the altitude of the object should be taken by the back observation; or if that be impracticable, the observer must endeavour to form as accurate an estimate as he can of the distance of the line which bounds his view in miles; and then having entered that distance in the margin of Table IV. opposite to it, under the altitude of the eye of the observer at the top, will be found the approximated allowance for dip, in minutes. Thus, if the line bounding the view were at the distance of two miles, and the eye of the observer 20 feet above the water, the dip would be 6′.

The allowance for dip, we need hardly observe, must be subtracted from the apparent altitude taken by the fore observation, but added to it when taken by the back observation of Hadley's quadrant.

2. *Of Refraction.*

The rays of light emitted by the heavenly bodies, during their passage through the atmosphere, are continually deflected in their course, and at last enter the eye of an observer at the surface of the earth, so as to make the object from which they proceed appear more elevated than it really is. (See Astronomy.) The allowance for refraction varies with the altitude of the object, and the state of the barometer, thermometer, and hygrometer. The correction for a particular state of the air, in respect of density and temperature, may be found by means of Table xlv. Astronomy; but the influence of humidity on the altitudes of the heavenly bodies has not been investigated with sufficient precision to be given in a tabular form.

In consequence of the inequalities of temperature which sometimes prevail at the surface of the water, and a few feet above it, refraction may occasion very considerable deviations from the allowance for the elevation of the observer above the sea, described under the head of *dip*. The errors arising from these causes vary exceedingly with the sudden changes produced on the temperature of the air, by the appearance or obscuration of the sun; though it is to be feared they are much too anomalous to admit of being duly estimated and corrected. The following general remarks on this subject, which are given by Rossel in Biot's *Astronomie*, may however prove useful.

1st, If the surface of the sea is warmer than the air, the altitude of an object corrected for dip, by the allowance in the table, will be too great; but if, on the contrary, the air is warmer than the surface of the sea, the corrected height will be too small. Hence, in the former case the usual allowance for dip is too little, and in the latter too great.

2d, When the temperature of the sea differs from that of the air, taken at the height of 3 to 6 feet above it, from 7° to 14° of Fahrenheit's scale, the error of the observed altitude may amount to 3′ or 4′; and a difference of 4° or 6° in the temperature may occasion an error of 1′ or 2′ in the altitude.

3d, The water at the surface of the sea being heated by the sun more slowly than the atmosphere, is colder than the air during the early part of the morning, and therefore, at that time, the usual allowance for dip, which is deduced from the ordinary refractive power of the air, is too great. In the evening an opposite state of things takes place, and the common allowance for dip is then too small. These conclusions are confirmed by the observations of Dr. Wollaston. See *Phil. Trans.* 1803.

The effect of refraction being to increase the apparent altitudes of the heavenly bodies, the allowance for it must always be subtracted from the observed altitude, or added to the apparent zenith distance.

Example.—When the apparent altitude of the sun's centre was 24° 3′, what was its true altitude, the barometer at the time standing at 30.85 inches, and the thermometer at 72° Fahrenheit?

The altitude being 24° 3′, the zenith distance is 65° 57′, the correction for which in Tab. xlv. Astronomy, is 2′ 2″.6, being the refraction when the barometer is at 29.6, and thermometer at 50°; but the barometer being 1.25 inches higher than the state of the atmospherical pressure for which the Table is calculated, an allowance of 3″.7 for every $\frac{9}{10}$ths of an inch, must be made, to adapt it to the supposed height of the barometer.

.9 in. : 1.25 in. = 3.″7 : 5″.1, which is additive, because the barometer is higher than in the table.

Again, the variation in the Table for every 20° of the thermometer, is 5″.9, and the thermometer standing 25° higher than 50°, for which the table is computed, we have

20° : 25° = 5″.9 : 7″.3 which is subtractive, because the temperature is higher than that given in the table.

Hence the refraction is 2′ 2″.6 + 5″.1 — 7″.3 or 2′ 0″.4.

Apparent zenith distance	65°	57′	0
Refraction - - -	+	2	0.4
	65	59	0.4
	90		
Corrected altitude	24	0	59.6

When the observer is not furnished with a barometer or thermometer, the correction for refraction in the table for the corresponding zenith distance will, for the most part, answer sufficiently well for all nautical purposes. Thus, in the above example, the refraction found by immediate inspection in the table, differs only 2″ from the corrected refraction, after a due allowance has been made for the changes produced by the differences of pressure and temperature.

3. *Of the Semidiameters of the Sun and Moon.*

Astronomical calculations connected with the positions of the sun and moon, having a reference to the centres of these luminaries, it becomes necessary, when their altitude or angular distance is to be determined by observation, that their semidiameters should be accurately known, in order that they may be added to, or subtracted from, the quantities obtained by actual measurements, which must always have a regard, in the first instance, to some part of their discs.

These semidiameters, which are in fact the halves of the angles subtended by the sun and moon, vary with the distance of these bodies from the earth; but being inserted in the Nautical Almanack at intervals, between which they may be considered as increasing or decreasing uniformly, it is easy to compute them for any intermediate instant of time.

When the altitude of the sun or moon is taken by a fore-observation with Hadley's quadrant, and the lower limb is brought in contact with the horizon, the semidiameter of the observed body must be added to its altitude; but if the upper limb be made to coincide with the horizon, the semidiameter must be subtracted. On the contrary, if the altitude be taken by a back observation, and the apparently lower limb of the sun or moon be brought in contact with the horizon, the semidiameter must be subtracted; but added, if the apparently upper limb be made to coincide with the horizon.

The diameter of the moon, besides the synodical changes to which it is liable, receives a small augmentation as she advances towards the meridian, in consequence of her diminished distance from the place of the observer. The requisite correction is contained in Table XXXII. Astronomy. The horizontal semidiameter of the moon, on the given day, taken from the Nautical Almanack, being found at the top of the table, the quantity to be added to it is to be sought immediately under it, and opposite the moon's altitude.

Sect. II. *Of the Corrections to be applied to Quantities taken from the necessary Tables.*

1. *Of Parallax.*

If all the heavenly bodies were very remote, and equally distant from the earth, their relative positions with respect to one another would be little affected whether they were viewed at the centre, or the surface of our globe; but some of them, particularly the sun and the moon, being considerably nearer than the stars, a sensible alteration of their place, in reference to the last mentioned bodies, is produced by a change of position on the surface of the earth. This circumstance has rendered it necessary for astronomers to refer their observations to the centre of the earth, the only point which can be regarded as alike common to its different inhabitants, and to the globe itself. See Astronomy. The difference between the altitude of an object, according as it is made to refer to the true, or the sensible horizon, is called the *parallax in altitude*, and is the same as the angle subtended by the semidiameter of the earth, drawn at right angles to the real horizon of the observer.

The parallax of an object, when it is in the horizon, is the greatest possible, and is called the *horizontal parallax*. In the case of the moon, the horizontal parallax for the mean parallel of 45°, varies from 61′ 29″ to 53′ 45″, and is given in the Nautical Almanack for every noon and midnight. Its value for any intermediate instant of time may be accurately computed by interpolation, according to the method of differences; but as the variation is nearly uniform for a short interval of time, it will generally be obtained with sufficient accuracy, by taking the difference between the parallax for the noon and midnight before and after the given time, and calculating a proportional part for the elapsed time, which must be added to, or subtracted from, the parallax for the preceding noon or midnight, according as the parallax is increasing or decreasing. Thus, if it were required to find the moon's horizontal parallax at Greenock, on the 15th. Feb. 1820, at 18 h. 15 m. which corresponds to 15 minutes past 6 o'clock in the morning of the 16th day, it would be necessary to take from the Nautical Almanack the horizontal parallax for the midnight of the 15th and the noon of the 16th day. The former is 55′ 0″, and the latter 54′ 49″; so that the difference for 12 hours is 11″. The proportional part for 6 h. 15 m. the time elapsed from midnight, is found to be nearly 6″ by saying 12 h. : 6h. 15m=11″ : 6″. As the parallax is decreasing, 6″ must be subtracted from 55′ 0″, which reduces it to 54′ 54″. When the utmost accuracy is aimed at, a correction must be applied on account of the oblate figure of the earth, which renders the parallax less as the latitude increases. This correction, which may be neglected in ordinary cases, is found for every 6° of latitude in Table xxx. Astronomy.

The correction from this table to be applied to the parallax deduced by the above example, would be 9″ subtractive; that number being found under 54′, the nearest equatorial parallax, and opposite 51½°, the nearest in round numbers to the latitude of Greenwich. Hence the corrected parallax would be 54′ 54″—0′ 9″, or 54′ 45″.

As the altitude of an object increases, its parallax diminishes, till it becomes nothing at the time the object reaches the zenith. The law, according to which the diminution proceeds, is easily determined. Let C (Plate CCCCIV. Fig. 30.) be the centre of the earth; A the place of an observer; AH the sensible horizon, and C *h* the real or true horizon; also let H be an object in the horizon. The altitude of H, seen from A, would evidently be nothing; but its altitude at C would be the angle HC *h*, or its equal the angle AHC.—This angle is the horizontal parallax. Let the object now be at B; its apparent altitude at A is the angle BAH, whereas its altitude at C is the angle BC*h*, which exceeds the former by the angle ABC, the parallax in altitude. But in the two triangles AHC and ABC, we have

CH : AC=radius : sine AHC,
And BC : AC=sine BAC : sine ABC;
Hence radius : sine BAC=sine AHC : sine ABC.
But sine BAC=sine BAZ=cos. BAH;

Also angle AHC is the horizontal parallax, and angle ABC the parallax for the altitude BAH.

Therefore radius : cos. BAH=sine AHC : sine ABC; that is, *radius is to the cosine of the altitude, as the sine of the horizontal parallax to the sine of the parallax in altitude.*

This analogy must be employed to find the parallax corresponding to any observed altitude, after the latter has been duly corrected for dip and refraction.

Example. When the apparent altitude of the moon's centre, after the proper allowances have been made for dip and refraction, is 62° 15′, what is the parallax in altitude, the horizontal parallax being 58′ 41″?

Radius - - - -	10.
Is to cos. alt. 62° 15′ -	9.66803
As sine hor. par. in alt. 58′ 41″	8.23221
	17.90024
To sine par. in alt. 27′ 19″	7.90024

The parallax of the moon, as well as the parallax of the sun, being always a very small quantity, and the sines of very small arches differing but little from the arches themselves, the parallax in altitude both of the sun and moon may be computed with sufficient accuracy, by multiplying the horizontal parallax by the natural cosine of the altitude. Thus in the above example,

Par. in alt.=hor. par. × nat. cos. 62° 15′=58′.7×.4656= 27′.33=27′ 20″ nearly.

The effect of parallax being to render the altitude of an object less than it really is, the correction for it must always be added to the apparent altitude.

2. *Of difference of time as estimated at two places, and the necessary corrections which it implies.*

The various quantities inserted in the Nautical Almanack being computed to particular periods of time, all of which have a reference to the meridian of Greenwich, if any of them are to be used in a calculation for a different meridian, a suitable correction must be made for the difference of longitude, to adapt them to this change of circumstances. The time which the earth takes to make a revolution on its axis in respect of the sun, or, in other words, the time which elapses between two consecutive transits of the sun across the meridian of any place, being 24 hours, it follows that 24 hours in time must correspond to 360° of longitude. When the sun is on the first meridian, all the places under this meridian on one side have noon, whereas all those places which are under the opposite half of it must have midnight. In like manner, since an hour of time corresponds to 15° of difference of longitude, every place lying under a meridian 15° to the eastward of the first meridian, must have its apparent time, according to the sun, an hour in advance of the time at Greenwich; so that these places will have 1 o'clock when it is only noon at Greenwich. On the contrary, every place lying under a meridian 15° to the westward of the first meridian, must have its apparent time an hour later than the time at the first meridian, and therefore must reckon 11 o'clock when it is noon at Greenwich. So that, in general, if a place be to the eastward of the first meridian, the time at Greenwich corresponding to a given hour at that place will be found, by subtracting from it the portion of time answering to the difference of longitude, by allowing an hour for every 15°; but if to the westward, by adding to it a like proportional quantity.

From the simple relation subsisting between the difference of time at two places and their difference of longitude, it is obvious that the important problem of determining the difference of longitude between two places may be resolved into some method of finding by observation the hour of the place whose longitude is sought, and the hour at the same time of the first meridian. The former is easily ascertained by various means; the latter is found with greater difficulty, but it may be computed from accurate observations made, at a particular instant of time, on the angular distance between the moon and the sun, or between the moon and certain fixed stars, as we shall afterwards fully explain. Several of the quantities, however, to be employed in the calculation, being taken from the Nautical Almanack, and adapted, as we have already stated, to the meridian of Greenwich, must be corrected for difference of longitude in so far as the longitude is known. For this purpose, it is not necessary to be sure of the longitude within less than 10° or 12°, as the daily change of the quantities to be corrected is for the most part so small, that a mistake in the time, not exceeding an hour, can seldom occasion an error of great importance in the result of the calculation. Before applying these corrections, we shall give the methods of converting degrees and time mutually into each other.

To convert Time into corresponding Degrees, &c.

Multiply the given time by 15, carrying at 60 in the different denominations; or multiply successively by 3 and 5.

Reduce 3 h. 48 m. 12 s. to degrees, &c.

3 h.	48 m.	12 s.
		5
19	1	0
		3
57	3	0

Hence the given time answers to 57° 3′ 0′.

To convert Degrees, &c. into corresponding Time.

Multiply the given degrees, minutes, and seconds by 4, reckoning the seconds, thirds; the minutes, seconds, and the degrees, minutes.

Reduce 56° 13′ 12″ to hours, minutes, &c.

56° 13′ 12″
4
3 h. 44′ 52″ 48‴.

Hence the corresponding time is 3 h. 44′ 52″ 8.

3. *Reduction of the Quantities in the Nautical Almanack to a given time, under the same or a different Meridian.*

The general rule to be observed in these reductions is, first to find the time at Greenwich corresponding to the hour of the given place, and then to take from the Nautical Almanack the element to be corrected, for the nearest time immediately before and immediately after the reduced time. The difference in the state of it at these two instants of time, will be the change for the interval between them; and a proportional part of it being found for the excess of the reduced time above the next lowest time in the table, and added to or subtracted from the state of the element answering to the next lowest time, the sum or difference, according as it is increasing or diminishing, will be the quantity corrected to the reduced time.

Examples.—I. What is the declination of the sun for the noon of a place which is in longitude 36° 15′ W. on the 24th May 1821?

36° 15′ reduced to time become 2 h. 25 m. so that when it is noon at the given place it is 2 h. 25 m. past it at Greenwich.

Sun's declin. May 24, 1821, noon of Greenwich,	20°	45′ 56″	N.
.... 25, ...	25	55 55	N.
		9 59	

Then 24 h. : 2 h. 25 m.=9′ 59″ : 1′ 0″ correction for 2 h. 25 m. which being added to 20° 45′ 56″, gives 20° 46′ 56″ for the declination at the given time.

II. Required the sun's declination at 9 h. 30 m. A. M. on the 15th of October 1821, for a place which is 76° 15′ E. from Greenwich.

9 h. 30 m. A. M. of the civil day corresponds to 21 h. 30 m. reckoned from the noon of the preceding day; and 3 h. 5 m. the time corresponding to the difference of

longitude, being subtracted from 21 h. 30 m. gives 18 h. 25 m. for the time at Greenwich, Oct. 14.

Sun's declin. Oct. 14, 1821, for noon of Greenwich,	8°	7′	53″	S.
.... 15, ...	8	30	12	S.
Change in 24 h. - - - - -		22	19	

Then 24 h. : 18 h. 25 m. = 22′ 19″ : 17′ 8″, correction for 18 h. 25 m. which being added to 8° 7′ 53″, because the declination is increasing, gives 8° 25′ 1″ S. for the sun's declination at the given place and hour.

III. What is the moon's declination at a place 135° 20′ east from Greenwich, at 15 m. past 10 o'clock on the evening of the 29th June, 1821?

The long. 135° 20′ reduced to time is 9 h. 1 m. 20 s. which subtracted from 10 h. 15 m. leaves the 13 m. 40 s. for the time past noon at Greenwich on the given day.

Moon's declin. June 29, 1821, for noon of Greenwich	27°	48′	N.
.... midnight	27	0	N.
Change of declination in 12 h. - - - -	0	48	

Hence the correction for 1 h. 13 m. 40s. is 5′ subtractive, and being taken from 27° 48′, leaves 27° 43′ for the corrected declination.

IV. Required the right ascension of the moon for a place 153° 45′ W. of Greenwich, on the 19th September, 1821, at 15 m. past 5 o'clock in the morning.

The Long. 153° 45′, reduced to time, is 10 h. 15 m. which, being added to 17 h. 15 m. the time at the given place, reckoned from the noon of the 18th, gives 27 h. 30 m. being 3 h. 30 m. past the noon of Greenwich on the 19th.

Moon's R. A. Sep. 19, 1821, for noon of Greenwich	98°	46′
.... midnight	106	9
Change of R. A. in 12 h. - - - - -	7	23

Hence the correction for 3 h. 30 m. is 2° 9′ additive, and being added to 98° 46′, gives 100° 55′ for the corrected right ascension.

V. Required the moon's horizontal parallax on the 10th July, 1821, at 40 m. past 9 o'clock in the evening, for a place whose longitude is 137° 40′ W. from Greenwich.

The Long. 137° 40′, reduced to time, is 9 h. 11 m. and being added to 9 h. 40 m. the hour of the day at the given place, gives 18 h. 51 m. for the time at Greenwich.

Moon's hor. par. July 10, 1821, for midnight of Green.	54′	14″
.... 11, ... noon.	54	19
Change of hor. par. in 12 h. - - - - -	0	5

Hence the correction for 6 h. 51 m. the time past midnight, is 3″ nearly, which, being added to 54′ 14″, gives 54′ 17″ for the corrected horizontal parallax.

The positions of the fixed stars (see ASTRONOMY,) are determined either by their latitudes and longitudes, or by their declinations and right ascensions. The latter method is best adapted to the purposes of the mariner, as being more immediately connected with the great circles, by means of which he estimates his geographical place. In consequence, however, of a slow motion which the equinoctial points have from east to west, amounting to about 50″ annually, (see ASTRONOMY,) both the right ascensions and declinations of the stars are subject to a small change, which, though very inconsiderable for a short period of time, yet, after a lapse of years, becomes sufficiently great to affect, in a very material degree, their place in the heavens, in reference to the equator. In the catalogues of the stars, the right ascensions and declinations of these bodies are brought up to some particular year; but the means are given of adapting these quantities to any other period of time, by annexing in a separate column the annual changes of each, with the sign + prefixed, to denote that it is additive for following years, or —, if it be subtractive. The right ascensions and declinations are to be understood, as referring, in the catalogue in which they are given, to the commencement of the year.

The right ascension of a star, for any time subsequent to the year for which the table is adapted, is easily found by adding to the right ascension for that year, the product of the annual change of right ascension, by the number of elapsed years and fractional parts of a year. The declination is found in the same manner: only the correction for the elapsed time is added when the sign of annual variation is +, and subtracted when it is —.

EXAMPLES.—Required the R. A. of the star Regulus for the 15th June 1836.

R. A. of Regulus in Naut. Almanack, Jan. 1828,	9h	58′	40″
Correction for $18\frac{1}{2}$ years, the annual var. being 3″.21		-	59.5
Corrected R. A. for given time - - - -	9	59	39.5

What is the declination of Arcturus for the 5th Aug 1850?

Declination of Arcturus, Jan. 1. 1818, -	20°	8′	5″9.	N.
Cor. for $32\frac{7}{12}$ years, the annual var. being 78″.99		10	18.8	
Cor. dec. for given time - - - -	19	57	47.1	N.

CHAP. III.

Of finding the Latitude of a Place.

The methods of finding the latitude of a place by celestial observation may be indefinitely varied; but, on the present occasion, we can only consider such as are the easiest, as well as the most practicable at sea.

The method most generally resorted to, because it is the simplest, is by an observation of the meridian altitude of the sun, or any of the other heavenly bodies whose declination is known. But as this method, though the best when it can be reduced to practice, may occasionally be rendered unavailable by the obscuration of the heavenly object, at the time of its meridian transit, we shall give a second method, that may be considered as supplementary to it, by which the meridian altitude may be determined with considerable accuracy, and consequently also the latitude, provided an altitude of the object can be obtained within 10 minutes of the time of its passing the meridian. Lastly, We shall give a third method, which may be employed when the other two fail, namely, by means of two altitudes of a heavenly body, and the elapsed time between the observations.

SECTION I.—*Method of finding the Latitude by the Meridian Altitude of a known heavenly body.*

It has been shown in ASTRONOMY, that the latitude of a place is always equal to the altitude of the nearest pole, and also that the distance of the equator from the horizon, that distance being reckoned on the celestial meridian of the place, is equal to the co-latitude. This obvious proposition furnishes the following easy method of finding the latitude from the meridian altitude of a known heavenly object.

1. Let the altitude be reckoned north or south, according as the object is to the north or south of the observer, at the time of its meridian transit.

2. If the declination be of a different name from the altitude thus denominated, subtract it from the altitude, duly

corrected for dip, refraction, &c. and the difference will be the complement of the latitude, of the same name with the declination.

3. If the declination is of the same name with the altitude, their sum, when less than 90°, is the complement of the latitude, which, in that case, is of an opposite name with the declination; but when greater than 90°, the excess is the complement of the latitude, of a contrary name with the declination.

EXAMPLES.

1. *By the Meridian Altitude of the Sun.*

At a place in Long. 63° 18′ W. the sun's meridian altitude, by a fore observation, in which the lower limb was brought to the horizon south of the observer, was 29° 35′; required the latitude, the observation having been made on the 18th July, 1820, when the eye of the observer was 35 feet above the ocean.

The dec. of the sun for the noon of Greenwich, July 28, 1820, is, by the Naut. Almanack, 21° 1′ 52″ N. and the daily diff. at that time being 9′ 46″, the correction for 4 h. 13 m. (the diff. long. reduced to time,) is 1′ 43″. Hence the corrected dec. is 20° 59′ 9″.

Alt. sun's lower limb - -		29° 35′ 0″
Refraction - -	1′ 41″	7 5
Dip for 35 feet - -	5 42	
		29 42 5
Sun's semidiameter	15 46	15 54
……… parallax - -	8	
True alt. sun's centre - - -		29 26 11 S.
Corrected declination - -		20 49 9 N.
Colatitude - - - -		8 27 2
		90
LATITUDE - - - - -		81 32 58 N.

2. *By the Meridian Altitude of the Moon.*

May 15, 1819, being in longitude 79° 42′ E., the moon was observed to cross the meridian south of the observer, 12 minutes past 5 o'clock in the morning, when the altitude of her lower limb was observed to be 59° 16′. Required the latitude, the eye of the observer having been 15 feet above the sea.

The longitude, reduced to time, is 5 h. 19 m. and the time of the observation, reckoned from the preceding noon, being 17 h. 12 m. the time at Greenwich is 17 h. 12 m.—5 h. 19 m. = 11 h. 53 m. of May 14th.

The moon's hor. par. for the 14th at noon, is, by the Nautical Almanack, 59′ 48″, and at midnight 59′ 39″: Hence her hor. par. at 11 h. 5 m. past noon may be taken at 59′ 39″. From which her par. in altitude is found to be 30′ 29″.

Her declination, corrected in like manner, is 26° 20′ S.; and her semidiameter 16′ 17″; to which 14″, the equation from Table XXXII. ASTRONOMY, for the altitude, being added, becomes 16′ 31″.

Alt. moon's lower limb . .		59° 16′ 0″
Dip for 15 feet . .	3′ 42″	4 16
Refraction . . .	34	
		59 11 44
Moon's semidiameter	16 31	47 0
Parallax . . .	30 29	
True alt. moon's centre . .		59 58 44 S.
Corrected declination . .		26 20 0 S.
		86 18 44
Colatitude		90
LATITUDE		3 41 16 N.

3. *By the Meridian Altitude of a Planet, or Star.*

About the beginning of November 1820, the meridian altitude of Aldebaran was observed to be 72° 30′; the eye being 30 feet above the water, and the star south of the observer. Required the latitude of the place of observation?

In the Nautical Almanack, the north polar distance of Aldebaran was 73° 51′ 55″.5, at the beginning of January 1818; and as the annual variation is then stated to be—7″.95, the change for 2 years and 10 months, or $2\frac{5}{6}$ years, is—22″.6. Hence the corrected N. P. distance is 73° 51′ 32″.9, and consequently the declination is 16° 8′ 27″.1 N.

Merid. altitude of Aldebaran . . .		72° 30′ 0″
Refraction .	0′ 18″	0 5 30
Dip for 30 f. .	5 12	
True altitude of Aldebaran		72 24 30 S.
Declination		16 8 27 N.
Colatitude		56 16 3
		90
LATITUDE		33 43 57 N.

SECT. II.—*Method of finding the Latitude by the Altitude of a heavenly body, taken near the Meridian.*

To apply this method with advantage, the time must be previously determined, (in a way we shall afterwards describe,) so that the watch may not deviate more than a minute from the instant of true noon. During the interval between 10 minutes before, and 10 minutes after noon by the watch, let as many altitudes as possible be observed, and the times at which they are taken carefully noted by the watch. Add together the several altitudes, and divide their sum by the number of them, for a mean altitude. Correct this altitude for dip, refraction, &c. and retain the result, in order that it may afterwards be augmented by a quantity to be found in the following manner, by means of the computed latitude and the sun's declination. Take the difference between the time of each observation and noon, for the several altitudes, and search in Table VI. for a corresponding multiplier to each, by finding the minutes at the top, and the seconds at the side: Under the one, and opposite the other, is its multiplier. Add together these multipliers, and divide their sum by their number, as in the case of the altitudes, calling the result the *mean multiplier.* Next search in Table V. for the computed latitude at the side, and the declination of the object at the top; and opposite the one, and under the other, will be found the change of altitude of the object, for a minute, before or after the time it reaches the meridian. Multiply this quantity by the mean multiplier, and the product will be a correction, in seconds, to be added to the mean altitude, to obtain the meridian altitude. The meridian altitude being thus determined, the latitude is found as in Sect. I.

If the time given by the watch can be relied upon, a single altitude with the corresponding interval from noon is quite sufficient; but if the ship has altered her longitude since the watch was adjusted, a suitable correction must be made for the difference, as explained in Sect. II. Chap. II. p. 203.

EXAMPLE.—April 23, 1820, being in lat. 32° 15′. N. long. 73° 48′ by account, it was ascertained that at 9 h. 30 m. A. M. the watch was 18 m. 15 s. behind solar time; at noon, the ship having then altered her longitude 12′ W. the following altitudes of the sun's lower limb were observed, at the annexed times by the watch.

Altitudes.			Time by the Watch.		
69°	8′	10″	11 h.	32 m.	40 s.
69	12	30	11	36	12
69	15	20	11	42	0
69	14	10	11	45	10
69	9	30	11	50	5

Required the latitude, the eye of the observer having been 20 feet above the surface of the sea.

The sum of the altitudes is 345° 59′ 40″, which, divided by 5, the number of them gives 69° 11′ 56″ for the mean altitude.

The times, after correcting for the error of the watch, and making an allowance for the change of longitude, by adding to 18 m. 25 s. the time corresponding to 12′, viz. 48″, (because the meridian transit will happen so much later at a place 12′ more to the westward,) and then adding the sum 19 m. 13 s. to each of the above times, become

True Times.			Interval from Noon.		Multip. from Tab. VI.
11 h.	51 m.	53 s.	8 m.	7 s.	65.9
11	55	25	4	35	21.0
12	1	13	1	13	1.5
12	4	23	4	23	19.2
12	9	18	9	18	86.5
					5)194.1
Mean Multiplier					38.8

The change of altitude for one minute in Table V. for the computed latitude 32° 15′ and corrected declination, 12° 39′ 58″ N. by allowing for the difference of longitude, is 4″.9, which, multiplied by 38.8, gives 190″, or 3′ 10″ to be added to the mean altitude. The rest of the operation is then as follows:

Mean altitude of ⊙'s lower limb	69°	11′	56″	S.
Dip for 20 f. 4′ 18″ } Refraction 7 }	0	4	25	
	69	7	31	
⊙'s Semidiameter	0	15	56	
Mean alt. ⊙'s centre	69	23	27	
Correction *found above*	0	3	10	
Mer. alt. ⊙'s centre	69	26	37	S.
Declination	12	39	58	N.
Colatitude	56	46	39	
LATITUDE	33	13	21	N.

SEC. III.—*To find the Latitude by two Altitudes of the Sun, and the elapsed time between the observations, together with the Latitude by Account.*

CASE I.—*When both altitudes are taken at the same place.*

1*st*, Take half the sum, and half the difference of the two altitudes, duly corrected for dip, refraction, &c.; and having reduced the elapsed time to degrees, &c. take its half, and call it the half interval.

2*dly*, Add together the five following logarithms.

The log. cos. of one-half sum of the altitudes.
The log. sine of one-half diff. of the altitudes.
The arith. comp. log. sine of one-half interval.
The arith. comp. log. cos. of Declination.
The arith. comp. log. cos. latitude by account.
Their sum is log. sine of an arc.

3*dly*, Take the difference between this arc, and the one-half interval; half of this difference is half the time from noon, when the greater altitude was taken; or half of the sum is the time from noon when the less altitude was taken.

4*thly*, Add together the three following logarithms.

The log. cos. of the declination.
The log. cos. of the latitude by account.
Twice the log. sine of half time from noon, in degrees, &c.

The number corresponding to the sum, (rejecting the tens both in this and the preceding amount,) being doubled, is a correction, which, added to the natural sine of that observed altitude, half the time of which from noon was taken, gives the natural sine of the meridian altitude. The latitude is thence found, as in Section I.

If the latitude resulting from these operations differs much from the latitude by account, it will be proper to repeat the calculation, substituting the latitude found for the latitude by account, until the computed latitude agrees, either exactly or nearly, with the latitude used in the operation.

EXAMPLE.—June 4, 1819, in latitude by account 37° N. at 10 h. 29 m. A. M. by the watch, the corrected altitude of the sun was 65° 24′, and at 12 h. 31 m. the altitude was 74° 8′. Required the true latitude.

First alt. sun's centre	65°	24′
Second	74	8
Sum of altitudes	139	32
One-half sum of altitudes	69	46
Diff. of altitudes	8	44
One-half diff. of altitudes	4	22

The interval between the observations 2 h. 2 m. reduced to degrees, &c. and halved, is 15° 15′ and the declination, without making any allowance for difference of longitude, is 22° 22′ N.

Log. cos. one-half sum altitudes 69° 46′				9.53888
Log. sine one-half diff. altitudes 4° 22′				8.88161
Ar. comp. log. sine one-half interval 15° 15′				.57999
Ar. comp. log. cos. Decl. 22° 22′				.03397
Ar. comp. log. cos. lat. by account, 37°				.09765
Log. sine of an *arc*,	7°	47′	25″	9.13210
One-half interval,	12	15	0	
Difference,	7	27	35	
One-half diff.	3	43	47	=half time from noon when greater altitude was taken, in degrees, &c.

Log. cos. dec. 22° 22′		9.96603
Log. cos. lat. by account 37°		9.90235
2 Log. sine one-half time from noon 3° 43′ 47″		8.81325 8.81325
Log. one-half correction	.003125	7.49488
	2	
Correction	.006250	
Nat. sine gr. alt. 74° 8′	.961900	
Nat. sine of 75° 30′	.968150	

Hence the mean altitude is	75°	30′	S.
Declination	22	22	N.
Co. lat.	53	8	
	90		
LATITUDE	36	52	

There being little difference between the latitude found, and the latitude by account, it is unnecessary to repeat the operation.

When both the observations are taken on the same side of the meridian, the half interval is half the difference of the times from noon, and the first found arc is half the sum of the times from noon; but when the observations are taken on different sides of the meridian, the half interval is half the sum, and the first found arc half the difference of the times from noon. Hence, half the difference, added to half the sum, gives the time of the observation farthest from noon; and half the difference, subtracted from half the sum, gives the time of the observation nearest to noon.

The times indicated by the watch should be observed to seconds; and the most convenient time for making the observation is between three hours before, and three hours after noon. The interval between the observations should not exceed five hours, nor be less than the time from noon at which the greatest altitude is taken; and the accuracy of the watch should be such, as not to lead to an error of one minute in six hours.

The least altitude should not be less than 7° or 8°, nor its azimuth greater than 75°. The nearer the greater altitude is to the meridian, the more likely is the result to be correct, and its azimuth should not exceed 15°. When the meridian altitude of the sun is greater than 84°. this method of finding the latitude should not be employed.

Case II. *When the ship has changed her position during the interval between the observations.*

1*st*, Find the latitude by account, at the time the greatest altitude was taken.

2*dly*. Take the bearing of the sun by the compass, at the time the least altitude was observed, and also the difference between that bearing and the ship's course by the compass.

3*dly*, With this angle, or its supplement, if it exceeds 90°, and the distance run by the ship between the observations, find the difference of latitude in the traverse table.

4*thly*, Add the difference of latitude thus found, to the first altitude, if the angle between the sun and the ship's tract be less than 90°; but subtract it, if that angle be greater than 90°, to reduce the first altitude to what it would have been found by observation, had it been taken at the same place as the second.

5*thly*. With these altitudes thus adapted to the same zenith, the observed interval of time, and the declination and the latitude by account, when the greatest altitude was taken, find the meridian altitude, as in Case I. and compute the altitude accordingly.

Example.—June 6th, 1804, being in lat. 58° 14′ N. by account, at 10h. 54m. A. M. by the watch, the altitude of the sun's lower limb was 53° 17′, and at 1h. 17m. P. M. the altitude was 52° 51′, and bearing, by the compass, S. W. by W. The ship's course during the interval between the observations, was S. by W. ½ W. and rate of sailing eight knots. Required the true latitude at the time of observing the greater altitude, the height of the eye having been 16 feet.

The angle formed by the sun's bearing at 2d observation, and the ship's course, is the difference between 5 and 1½ points, or 3½ points; and the distance run during the interval between the observations, is 19m. The diff. lat. corresponding to that course and distance, is 15 miles nearly.

First alt. ⊙ lower limb	53°	17′
Dip. 4′ Refraction 1′		.5
	53	12
⊙ Semidiameter		16
True alt. ⊙ centre	53	28
Second alt. ⊙ lower limb	52°	51′
Dip. 4′ Refraction 1′		5
	52	46
⊙ Semidiameter	+	16
Reduction for change of ship's place	—	15
Corrected alt. ⊙ centre	52	47

$$\tfrac{1}{2}\text{ sum of alt.} = \frac{53^\circ 28' + 52^\circ 47'}{2} = \frac{106^\circ 15'}{2} = 53^\circ\ 7'\tfrac{1}{2}$$

$$\tfrac{1}{2}\text{ diff. of alt.} = \frac{53^\circ 28' - 52^\circ 47'}{2} = \frac{0^\circ 41'}{2} = 0^\circ 20'\tfrac{1}{2}$$

Also, ½ elapsed time 1h. 11½m. reduced to degrees, &c. is 17° 52′½.

Log. cos. ½ sum alts. 53° 7′½		9.77820
Log. sine ½ diff. alt. 0° 20′½		7.77534
Arith. comp log. sine ½ interval 17° 52′½		.51295
Arith. comp. log. cos. decl. 22° 40′		.63491
Arith. comp. log. cos. lat. by account 58° 14′		.27863
Log. sine of an *arc*	1° 22′½	8.38003
Half interval	17 52½	
Difference	16 30	
Half difference	8 15 = ½ time from noon,	

when the greater altitude was taken.

Log. cos. decl. 22° 40′		9.96509
Log. cos lat. by account 58° 14′		9.72137
2 log. sin. half time fr. noon 8° 15′		9.15683 9.15683
Log half correction	.01000 2	8.00012
Correction	.02000	
Nat. sine gr. alt. 53° 28′	.80351	
Nat. sine 55° 26′ 15″	.82351	

Hence, the meridian altitude is 55° 26′ 15″.

With this meridian altitude and the declination, the latitude is found to be 57° 13′ 45″, which, differing about 60m. from the latitude by account, renders a repetition of the operation necessary, the computed latitude being used in place of the latitude by account.

Sum of first four logs.		8.10140
Ar. com. log. cos. computed lat. 57° 14′		.26663
Log. sine of an arc	1 20¼	8.36803
Half interval	17 52½	
Difference	16 32¼	
Half difference	8 16	
Log. cos. dec. 22° 40′		9.96509
Log. cos. comp. lat. 57° 14′		9.73337
2 log. sin. 8° 16′		9.15770 9 15770
Log. half correction	.01032 2	8.01386
Correction	.02064	
Nat. sin. gr. alt.	.80851	
Nat. sine 55° 30′	.82415	
⊙ Merid. alt.		55° 30′ S.
⊙ Declination		22 40 N.
Co-latitude		32 50
		90
Latitude		57 10 N

The result differing now only about 4 miles from the latitude used in the calculation, may be considered as the true latitude.

When great accuracy is aimed at, the sun's declination must be duly corrected, not only for the difference of longitude, but the mean hour of the day to which the altitudes refer; and the elapsed time itself must be corrected for the difference of longitude which the ship may have made during the interval between the observations. If the ship's place be referred to the time of the greater altitude, the difference of longitude reduced to time must be added to the time of the least altitude, when the latter was observed east of the former; but subtracted from it, if the contrary. By this means, the time will be adapted, in both cases, as well as the altitudes, to the meridian of the place where the greatest altitude was taken. For the demonstration of the method of finding the latitude laid down in this Section, see *Spherical* TRIGONOMETRY.

CHAP. IV.

Methods of finding the Horary Angle, and the Altitudes of the Heavenly Bodies, by calculation.

The exact time, in reference to the meridian of a place, is one of the most important elements which enter into the calculation, not only of its latitude and longitude, but also of the altitudes and azimuths of the heavenly bodies. We have already described, at great length, (ASTRONOMY,) the more rigid methods by which the true time may be determined by observations on land; and we now propose to explain the means to be employed for ascertaining the same thing at sea, where less accuracy is attainable. The time being deduced from the altitudes of the heavenly bodies, the altitudes may, in their turn, be calculated by means of the true time, when the latter has been previously determined.

SECT. I—*To find the Horary Angle of a Heavenly Body.*

The astronomical day, being the interval of time between two successive passages of the sun's centre across the meridian, commences at noon, and terminates the following day at the same instant. It is divided into 24 equal parts, called hours, each of which corresponds to 15° of the equator, the portions of that circle measuring the horary angles formed by the different meridians.

The hours of the astronomical day, reduced to degrees, &c. correspond with the horary angle from noon to midnight; thus, four o'clock in the afternoon is, in regard to the sun, the same as the horary angle 60°; but from midnight to noon, the hours, when reckoned in the ordinary way, must be subtracted from twelve hours, and the difference reduced to degrees, &c. is the horary angle. In short, whether the time is reckoned by the civil or astronomical method, the interval from noon is always to be accounted the horary angle.

By the rotation of the earth on its axis, the sun, as well as the other heavenly bodies, seem to have a daily motion in an opposite direction. The angles of elevation which they possess, in reference to the horizon, are thus perpetually changing, from the moment they make their appearance in the east, till they finally disappear in the west. The change of altitude, however, is not uniform, being greatest at the instant the body passes the prime vertical, and gradually diminishing as it advances to the meridian. Hence, though the hour from noon may be obtained by means of an altitude of a known heavenly object, taken at any period of its daily revolution, the most suitable time will evidently be when its change of altitude is most rapid.

Together with the sun's altitude, or that of some other heavenly body, the latitude of the place of observation must also be known, to deduce, by calculation, the horary angle. When the altitude is taken at the time the object crosses the prime vertical, that is, when it is due east, or due west, any error in the latitude has less influence on the result, than when it is taken near the meridian. Unless circumstances render it absolutely necessary, the interval from noon, when the sun's altitude is observed, should not be less than two hours; though a good observation, taken an hour from noon, will serve to determine the time within ten seconds, provided the altitude is accurately known, and the sun's azimuth not less than 20°.

1. *To find the Horary Angle by the Altitude of the Sun.*

Having made the necessary corrections on the altitude, and the declination, arrange the elements of the calculation in the following order:

1st, Add together the latitude, the true altitude, and the polar distance, or co-declination. Take half their sum, and from the half sum subtract the true altitude.

2dly, Then add together

The arith. comp. log. cos. latitude
The arith. comp. log. sine, Polar distance
The log. cos. of the half sum
The log. sine diff. of half sum and true altitude.

3dly, Take half the sum of these four logarithms, and it will be the log. sine of half the horary angle in degrees, &c.

If the observation was made in the afternoon, the corresponding time to the horary angle will be the hour reckoned from the noon of the same day; but if it was made in the forenoon, the corresponding hour will be found by subtracting the horary angle in time, from 12 hours, according to the civil mode of reckoning time, or from 24 hours, according to the astronomical mode. In the last case, the time will be reckoned from the noon of the preceding day.

The time thus found, is what is called by astronomers *True time*, or *Apparent time*, to distinguish it from the time that would be indicated by a *chronometer*, or a true going clock, which is called *Mean time*. See ASTRONOMY.

EXAMPLE.—June 21, 1820, at 8 h. 20 m. A. M. being in Lat. 25° 13′ 20″ N. Long. 49° 15′ W. the altitude of the sun's lower limb was observed to be 39° 15′ 40″. Required the true or apparent time of the observation, the eye having been 18 feet above the surface of the water, and also the error of the watch?

App. alt. sun's lower limb		.	39° 15′ 40″
Refraction	0′ 17″		
Dip	4 6	. .	4 23
			39 11 17
Sun's semidiameter		. .	15 46
True alt. sun's centre		. .	39 27 3

The sun's declination, June 20, 1820, is, by the Nautical Almanack, 23° 27′ 43″, and the daily change being 15″, the correction for 20 h. 20 m. the astronomical time of the observation, reckoned from the noon of June 20, together with the difference of longitude in time 3 h. 17 m. is such as to bring it to the noon of June 21, nearly. Hence the corrected declination is 23° 27′ 58″, and Polar distance 66° 32′ 2″. The calculation is, therefore, as follows.

The latitude . . .		25° 13′ 20″
Sun's true altitude . .		29 27 3
Polar distance . . .		66 32 2
Sun		131 12 25
Half sum		65 36 12
Diff. alt. and half sum . .		26 9 9
Arith. comp. log. cos. lat.	25° 13′ 20″	.04351
Arith. comp. log. sine pol. dist.	66 32 2	.03749
Log. cos. ½ sum. . .	65 36 12	9.61600
Log. sine diff. alt. and ½ sum	26 9 9	9.64421
Sun		19.34121

½ sum = log. sine ½ hor. angle	27	55	45	9.67060
			2	
Horary angle .	55	51	30	

Which, reduced to time, is 3 h. 43 m. 26 s. and corresponds to 8 h. 16 m. 34 s. A. M. of the civil day, or to 20 h. 16 m. 34 s. reckoned from the noon of June 20th.

	h.	m.	s.
Time by the watch . . .	8	20	0
Apparent time	8	16	34
Watch before apparent time .	0	3	26

2. *To find the Horary Angle, by the Altitude of a known fixed Star.*

If the sun had no apparent motion among the stars, the difference between his right ascension, and the right ascension of a star, would be the difference of time between the periods of their passing the meridian; and since the right ascension of each is reckoned on the equator, from west to east, the star would pass the meridian before the sun, when its right ascension was less than that of the sun, but after it, when it was greater. If the horary angle of the star, therefore, was computed at any time when it had a given altitude, it would be easy to deduce from it the true time in reference to the sun's meridian transit. The only correction to be made on the time thus computed is but a slight one, on account of the apparent diurnal motion of the sun among the stars, by which his right ascension increases daily from the vernal equinox, when it is nothing, until he arrives, after the interval of a year, at the same point again, when it is 360°, or 24 hours. From these considerations we may deduce the following method of finding the horary angle by the altitude of a star.

Calculate the sun's right ascension for the estimated time, and longitude of the ship, by taking from the Nautical Almanack the right ascensions for the preceding and following noon, and adding a proportional part of their difference for the elapsed time, to the right ascension of the preceding noon. The sum will be the sun's right ascension for the estimated time nearly. If the altitude of the star has been observed to the west of the meridian, add its horary angle to its right ascension, in time, and the sum will be the right ascension of the meridian; but if it has been observed to the east of the meridian, subtract the horary angle from its right ascension, and the difference will be the right ascension of the meridian. Lastly, from the right ascension of the meridian, increased by 24 h. if necessary, subtract the sun's right ascension, and the difference will be the apparent time of observation. If the apparent time thus computed differ more than 10 minutes from the estimated time of the place of observation, by the watch, it will be proper to calculate a second time the sun's right ascension, or to add to, or subtract from the time already found, a proportional part of the sun's right ascension, according as the estimated time is less or greater than the computed time. It is almost unnecessary to observe, that the horary angle of a star is found in the same manner as that of the sun, the elements being the same in both cases, viz. the latitude of the place of observation, the true altitude of the star, and its correct polar distance.

August 15, 1819, at 10 h. 20 m. P.M. by the watch, being in Lat. 24° 15′ 30″ S. Long. 61° 20′ E. the altitude of Fomalhaut on the east side of the meridian was 53° 15′ 20″, the eye having been 28 feet above the surface of the sea. Required the apparent time of the observation.

		H.	m.	s.
R. A. of Fomalhaut, Jan. 1, 1808 .		22	47	33.97
Change in R. A. for 1 year 8½ months	+			57
Cor. R. A. of Fomalhaut, Aug. 15, 1819		22	47	59.67
N. pol. dist. of Fomalhaut, Jan. 1, 1818		120°	35′	4″
Change for 1 year 8½ months . .	—			32.6
Cor. N. pol. dist. of Fomalhaut, Aug. 15, 1819		120	35	31.4
		180		
Cor. S. pol. dist. . . .		59	25	28.6

The estimated time at the ship being 10 h. 20 m. and the time corresponding to the difference of longitude 4 h. 5 m. 20 s. the time at Greenwich, according to the watch, is 6 h. 14 m. 40 s.

		H.	m.	s.
Sun's R. A. Aug. 15, 1819, for meridian of Greenwich .		9	36	33
Change in R. A. for 6 h. 15 m. .		0	1	57
Sun's R. A. for estimated time at ship		9	38	30
App. alt. of Fomalhaut . .		53°	15′	20″
Refraction .	0′ 43″	0	5	41
Dip . .	5 0			
True alt. of Fomalhaut . .		53°	9′	37″
The latitude		24°	15′	30″
True alt. of Fomalhaut . .		53	9	37
Pol. dist.		59	25	29
Sum		136	50	36
½ Sum		68	25	18
Diff. of alt. and ½ sum . .		15	15	41

Arith. comp. log. cos. lat.	24°	15′	30″	.04015
Arith. comp. log. sine pol. dist.	59	25	29	.06502
Log. cos. ½ sum . .	68	25	18	9.56558
Log. sine diff. alt. and ½ sum	15	15	41	9.42032
Sum				19.09107
½ Sum = Log. sine ½ hor. angle	20°	33′	34″½	9.54553
			2	
Horary angle .	41	7	9	

which reduced to time is 2 h. 44 m. 28 s.

	H.	m.	s.
Hor. angle of the star . .	2	44	28
Its R. A. . . .	22	47	40
R. A. of the meridian . .	20	3	12
Sun's R. A. . . .	9	38	30
App. time at place of observation	10	24	42
Time by the watch . .	10	20	0
Watch behind app. time .	0	4	42

For the method of finding the apparent time by equal altitudes of the sun, see ASTRONOMY.

SECT. II. *To find the Altitude of a Heavenly Body.*

The horary angle of an object, its polar distance, and the latitude of the place, are the three elements usually employed for calculating its altitude. The first of these quantities is known by the apparent time; and in the case of the sun is the time reckoned from the nearest noon, reduced to degrees, &c. When the horary angle refers to the moon or a star, it is found in the following manner: To the ship's time, which is supposed to be accurarely known, add the sun's right ascension duly corrected, rejecting 24 h. if the sum exceeds that number, and it will give the right ascension of the meridian. Then take the difference between the right ascension of the moon or star, and that of the meridian, and it will be the moon or star's horary angle.

The ship's time must be carefully distinguished from the time given by a chronometer, which generally has a reference to some other meridian. The ship's time is the time in regard to the noon of the ship's place, as determined by the last section, for computing the horary angle.

The polar distance, reckoned from the elevated pole of the hemisphere in which the ship is, and the horary angle, being both adapted to the time of the ship, the remainder of the calculation is to be performed in the following manner.

1. To the log. cos. of half the horary angle in degrees, &c. add half the log. sine of the polar distance, half the log. cosine of the latitude, and the log. secant (rejecting the index) of half the complement of the difference between the polar distance and the latitude. The sum will be the log. sine of an auxiliary angle.

2. From the log. cosine of this auxiliary angle, subtract the above log. secant of half the complement of the difference between the polar distance and the latitude, and the remainder will be the log. cosine of an angle, which being doubled, and then diminished by 90°, the difference will be the true altitude.

Example I.—May 25, 1820, being in Lat. 10° 45′ 30″ N. Long. 53° 47′ W. I was desirous of finding the altitude of Castor, at 9 h. 5 m. 15 s. by the watch, it having been ascertained the same day by an altitude of the sun, that the watch was 1 h. 20 m. 15 s. fast of apparent time. What was the altitude of the star at the time mentioned, the ship having changed her longitude 35 miles to the westward since the apparent time was determined?

	H.	m.	s.
Time by the watch	9	5	15
Watch fast	1	20	15
Apparent time	7	45	0
Correction in time for change of longitude	0	2	20
Corr. app. time of ship	7	42	40
Ship's longitude reduced to time	3	35	8
App. time at Greenwich	10	17	48

The sun's right ascension adapted to this time, is 4 h. 10 m. 9 s. Also the right ascension of Castor adapted to the year and month, is 7 h. 23 m. 7 s. and his north polar distance 57° 43′ 39″.

	H.	m.	s.
App. time of the altitude	7	42	40
Sun's right ascension	4	10	9
Right ascension of meridian	11	52	49
Right ascension of Castor	7	23	7
Castor's horary angle W. of meridian	4	29	42

which, reduced to degrees, is 67° 25′ 30″.

	°	′	″
Polar dist. of Castor	57°	43′	39″
Latitude	10	45	30
Difference	46	58	9
	90		
Complement diff.	43	1	51
One-half comp. diff.	21	30	55

	°	′	″	
Log. cos. ½ hor. angle	33°	42′	45″	9.92004
½ log. sine polar distance	57	43	39	4.96356
½ log. cos. latitude	10	45	30	4.99615
Log. sec. ½ comp. (*rejecting index*)	21	30	55	.03137
Log. sine of auxiliary angle	54	34	47	9.91112
Log. cos. auxiliary angle				9.76311
Log. sec. ½ comp. (*rejecting index*)				.03137
Log. cos.	57°	22′	18″	9.73174
			2	
	114	44	36	
	90			
True alt. of Castor	24	44	36	

Example II.—The circumstances being the same as in the last example, what was then the altitude of the moon?

	°	′	″	
R. A of the merid. formerly found 11 h 52′ 49″=	178°	12′	15″	
R. A. of the moon duly corrected	217	9	0	
Moon's hor. angle E. of Meridian	38°	56′	45″	
½ hor. angle	19	28	22	
Moon's declination corrected, is	18°	3′ S.		
	90			
Moon's N. Pol. dist.	108°	3′	0″	
Latitude	10	45	30	
Difference	97	17	30	
	90			
	7	17	30	
½ Complement of diff.	3	38	45	
Log. cos. ½ hor. angle	19°	28′	22″	9.97442
½ log. sine polar dist.	108	3	0	4.98904
½ log. cos. latitude	10	45	30	4.99615
Log sec. ½ comp.	3	38	45	.00088
Log. sine aux. angle 65° 55′ 50″				9.96049
Log. Cos. aux. angle				9.61051
Log. sec. ½ comp.				00088
Log. cos.	65°	58′	38″	9.60963
			2	
	131	57	16	
	90	0	0	
Moon's true alt.	41	57	16	

By means of a table of natural sines, and logarithmic versed sines, the altitude may be found more expeditiously in the following manner:

To the cosine of the latitude, add the sine of the polar distance, and the versed sine of the horary angle; the sum rejecting 20 is the logarithm of a number, which being subtracted from the natural cosine of the difference between the colatitude and polar distance, gives the natural sine of the altitude. The first example solved by these precepts will be as under:

Cos. lat. 10° 45′ 30″		9.99230
Sine pol. dist. 57° 43′ 39″		9.92712
V. sine hor. angle 67° 25′ 30″		4.78965
Log. of	51176	4.70907
Nat. cos. (colat.—P. dist.) 21° 30′ 5″	93033	
	41857 = nat. sine 24° 44′ 39″ alt. of Castor.	

The result differs only 3″ from the former calculation, and is greatly more simple.

CHAP. V.

OF THE LONGITUDE.

The various methods which have been proposed for finding the longitude at sea, depend either directly or indirectly on the determination of the difference of time between the meridian of the ship, and the first meridian; or any other from which the ship's departure may have been taken.

The time of the first meridian may be ascertained, either by an accurate chronometer previously adjusted to the mean time of that meridian, or by astronomical calculations, adapted in point of time to the first meridian. And the time at the meridian of the ship may be computed by the methods explained under the first section of Chap. IV. The difference of time between the first meridian, and the meridian of the ship being thus known, the difference of longitude is easily found by reducing the difference of time to degrees, &c. to be reckoned, of an *easterly* denomination, when the time of the ship exceeds the time of the first meridian, but *westerly* when the latter exceeds the former.

Sect. I.—*To find the difference of Longitude by a Chronometer.*

From the advanced state of the arts in modern times, the construction of chronometers or timekeepers has been carried to such a pitch of perfection, that these instruments, if they do not measure time with absolute exactness, move at least with sufficient uniformity for several months, to indicate, after a calculated correction, the instant of time at which they are observed, so as to answer, with the aid of a simple calculation of the apparent time, the purpose of determining the longitude. Before we can explain, however, the manner of using chronometers at sea for that important end, we must briefly consider the different modes which are usually employed for estimating time, without a correct knowledge of which we should be liable to commit very great errors in computing the longitude by these instruments.

The rotation of the earth on its axis being performed, at all seasons of the year, with perfect uniformity, the fixed stars appear to describe their diurnal revolution with the most undeviating regularity ; so that if a particular star be observed to cross the meridian on any night, at a given hour, it will be found to return to the meridian the following night, after an interval of 23 h. 56 m. 3 4 s. or 3 m. 56.6 s. earlier. This interval is called a *sidereal day* ; and time, computed in portions of it, is denominated *sidereal time.* By the apparent annual motion of the sun from west to east, the time which that luminary takes to perform a daily revolution, called a *solar* or *astronomical day*, is a little greater than a sidereal day ; insomuch that, in the course of a year, the sun crosses the meridian once less than the stars. Nor is the interval between two consecutive transits of the sun the same from day to day, but perpetually varying, so as to make the noon by the sun sometimes before and sometimes behind the noon that would be indicated by a perfect chronometer. This irregularity in the apparent motion of the sun arises from the obliquity of his path to the celestial equator, and the eccentricity of the earth's orbit ; but the difference which it causes between solar time, and the time marked by an accurate chronometer, being known, it will be easy at any time to deduce the one from the other. The difference alluded to, which is called the *equation of time*, is inserted for every day of the month, in the second page of each month, in the nautical Almanack, the word *add* being placed at the top of the column, when the equation is to be added to the time deduced from an observation of the sun, to bring it to the time of a perfect chronometer ; and *subtract*, when the contrary. The time indicated by the chronometer is denominated *mean time ;* while that deduced from an observation of the sun, or any of the heavenly bodies, is called *apparent time*, and by some writers, though very improperly, *true time*, as this appellation renders it liable to be confounded with mean time. In the nautical almanack, all the quantities are adapted to the apparent time of the meridian of Greenwich, except the immersions and emersions of Jupiter's satellites, which are calculated to mean time.

Chronometers are regulated to the mean time of some particular meridian, either by means of equal altitudes, (as explained in Astronomy,) or by calculating the horary angle by the methods laid down in Chap. IV. The proper allowance being made in either case, for the equation of time on the given day, by adding or subtracting it, as pointed out in the nautical almanack, the apparent time will be reduced to mean time ; and the chronometer may either be regulated accordingly, or the difference between it and the calculated mean time may be inserted, with the corresponding day of the month, in a small book kept for registering the going of the chronometer, and any thing else respecting it that may be deemed of importance. Thus, in the example given under the last chapter for finding the horary angle by the sun's altitude on the 20th June 1820, we would proceed to find the Mean time in the following manner :

	H.	m.	s.
Calculated apparent time, June 20th, .	20	16	34
Equation of time noon of June 21st, that being Greenwich time . .	+	1	20
Mean time	20	17	54
Time by the watch . . .	20	20	0
Watch before mean time . .	0	2	6

The equation of time is taken for June 21st, because the difference of longitude, together with the time of the observation, make the time when the altitude was taken to correspond almost exactly with the noon of Greenwich that day.

The chronometer being thus adjusted to mean time, or at least its deviation from it being known, a corresponding set of observations ought to be made at the same place, after a lapse of several days : and if the time by the chronometer is still found to agree with the mean time deduced from the calculated apparent time, or to differ from it by the same quantity as before, (in case no alteration was made on the chronometer) it would be a proof that the instrument was in the best order, and required no correction. But if, on the other hand, and which is far more probable, the chronometer should be found to have advanced before, or fallen behind mean time, by a certain number of seconds, or even minutes, let the interval between the observations be taken, and also the amount of the deviation, and from these let a proportional part be found for 24 hours. Thus, suppose the chronometer had been adjusted to mean time June 20, 1820, at 20 h. 40 m., that is, as early as possible, after the calculation of the horary angle for that day, and the reduction of the apparent to mean time ; and suppose farther it had been afterwards found by a similar calculation of the horary angle, from observations made at the same place, July 2, at 5 h. 15 m. 10 s. it had retarded 3 m. 12 s. Then the interval between June 20 d. 20 m. 40 s. and July 2d, 5 h. 15 m. 10 s. being 9 d. 3 h. 40 m. + 2 d. 5 h. 15 m. 10 s. or 11 d. 8 h. 55 m. 10 s.

11 d. 8 h. 55 m. 10 s. : 1 d.=3 m. 12 s. : 16.88 seconds.

Hence the retardation of the chronometer would, in the above case, be 16.88 seconds a day. The daily deviation of the chronometer, which is called its *rate*, being thus known, the amount of the deviation at any subsequent period from the mean time of the meridian to which it was originally regulated, may be computed by multiplying the daily rate by the elapsed time in days, and fractional parts of a day. Let it be supposed, for example, that the chronometer had been duly regulated to the noon of Portsmouth, February 8, 1820, its rate having been previously found, by the method we have explained, to be 7.56 seconds in advance, and it were required to find the mean time of Portsmouth, June 1, 1820, at a place in longitude 72° 12′ west from Greenwich, by account, where the chronometer at noon, by mean time, gave the time 4 h. 53 m. 12 s.

The interval of time between Feb. 8, 1820, and June

1, 1820, (it being leap-year) is 114 days. Then 7.″56 ×114=861.″8 = 14 m. 21.8 s. to which adding 1.″4 for the small proportional part corresponding to the time past noon, that is, in the present case, for the difference between 4 h. 53 m. 12 s. and 14 m. 21.8 s. the whole acceleration of the chronometer, is 14 m. 23 s.

	H.	m.	s.
Time by the chronometer .	4	53	12
Acceleration . . .	0	14	23
Mean time of Portsmouth .	4	38	49

which reduced to degrees, &c. gives 69° 42′ 15″ west from Portsmouth. The mean time of Portsmouth being thus found, together with the ship's longitude in reference to that place, which is *west*, because the ship's time is behind the time at Portsmouth, the longitude reckoned from the meridian of Greenwich is easily determined.

Long. of Portsmouth . . .	1°	6′	1″	W.
Diff. of long. between ship and Portsmouth	69	42	15	W.
Long. of ship, in reference to Greenwich	70	48	16	W.

Instead of having the time of the chronometer regulated to the mean time of the place from which the ship takes her departure, it will, in general, be more convenient to have it adapted to the noon of Greenwich. This can easily be done at any place, the longitude of which is well established, by making an allowance of time corresponding to the difference of longitude between the place and the first meridian. Thus, suppose the sun's horary angle had been found, by a set of good observations at Plymouth, to be 4 h. 25 m. 36 s. on the 15th Oct. 1820, at the instant when the chronometer gave 4 h. 1 m. 15 s. and it were required to find the correction to be made on the chronometer to adapt it to the meridian of Greenwich.

	H.	m.	s.
App. time at Plymouth . . .	4	25	36
Equation of time (*subtractive*) . .	0	14	9.7
	4	11	26.3
Long. of Plymouth 4° 7′ 31″ W. in time .	0	16	30.0
Mean time of Greenwich nearly . .	4	27	56.3
Correction of equation of time for interval from noon	0	0	2.4
Mean time of Greenwich . .	4	27	53.9
Time by the chronometer . .	4	1	15
Chronometer behind mean time of Greenwich	0	26	38.9

In making the observations for computing the sun's horary angle, for the purpose of regulating the chronometers, every precaution should be employed that can insure accuracy in the result. The observer should take the necessary altitudes as soon as the season of the year will permit, after the sun has passed the prime vertical in the morning, or before he has reached it in the evening; and instead of being satisfied with a single altitude, he should take four or six of them in close succession, at as short intervals as just to leave sufficient time to read off, without confusion, the indications of the instrument; and the time of each observation should be carefully noted by an assistant, either by means of the chronometer itself, or a good watch furnished with a second hand, and compared with the chronometer before and after the observations. The sum of the several altitudes, and also the sum of the corresponding times, being each divided by the number of observations, a mean altitude, with its corresponding time, will be obtained, which will probably be nearer the truth than any of those actually observed, taken singly. The mean altitude, thus found, being duly corrected for refraction, dip, &c. is to be used in the calculation of the horary angle for adjusting the chronometer. It might even be recommended to take two or three sets of such observations on the same day, at an interval of a quarter of an hour between each set, and to calculate the horary angle for each of them separately, making due allowance for the change of declination, according as it is increasing or decreasing. Let the corresponding times to the several horary angles, reckoned from the preceding noon, be then added together, and divided by the number of sets of observations. The mean thus deduced being corrected for difference of longitude; the equation of time for the preceding noon; and the proportional part of the equation of time for the interval between noon and the approximated time, thus computed, the result will be the mean time of Greenwich at the instant corresponding to the mean of the times given by the chronometer. The difference will, therefore, be the deviation of the chronometer before or behind the time at Greenwich, according as the mean of the times of the chronometer is greater or less than the mean result deduced by calculation.

To illustrate this by example, let us suppose that on the 26th Sept. 1820, the following sets of observations had been made in the morning at Leith, with the view of regulating a chronometer to the mean time of Greenwich.

	Means of Chronometer at the instant of Observations.			Calculated Horary Angles, in Time, from Means of observed Altitudes.			
1st set.	19 h.	30 m.	29 s.	19 h.	45 m.	37 s.	from preceding noon.
2d do.	19	48	37	20	3	46	
3d do.	20	1	16	20	16	26	

In the Nautical Almanack the equation of time for Sept. 25, 1820, is 8 m. 24.2 s. *subtractive*, and the daily difference+20″·3, the equation of time being increasing; also the difference of longitude between Leith and Greenwich being 3° 11′ W. the corresponding time is 12 m. 44 s. Hence the calculation will be as follows:

	H.	m.	s.
Hor. angle, in time, by 1st set of observations,	19	45	37
. . . 2d, . .	20	3	46
. . . 3d, . .	20	16	25
	3)60	5	49
Mean of the several times . .	20	1	56.3
Diff. of long. between Greenwich & Leith	+	12	44
	20	14	40.3
Equation of time Sept. 25, 1820, noon, —		8	24.2
Approx. mean time of Greenwich .	20	6	16.1
Cor. of equation of time for 20 h. 6 m. —			17 0
Cor. mean time of Greenwich .	20	5	59.1
Mean of the times by chronometer .	19	46	47.3
Chronometer behind mean time of Greenwich	0	19	11.8

If the equation of time be *additive*, and increasing, the proportional part of it for the interval from the preceding noon is to be added; but if decreasing, the proportional part is to be subtracted. In like manner, if the equation of time be *subtractive*, and increasing, the proportional part of it for the interval from the preceding noon is to be subtracted; but if decreasing, the proportional part is to be added to the approximated mean.

The calculation of the immersions and emersions of Jupiter's satellites, as laid down in the Nautical Almanack, being adapted to the mean time of Greenwich, the observation of these phenomena affords the means of ascertaining, on land, the state of the chronometer with respect to the mean time of the first meridian. The observed time by the chronometer, after making an allowance for its rate, should always, if it had been previously regulated to the mean time of Greenwich, correspond exactly with the calculated time of the immersion or emersion in the Nautical Almanack; and therefore, if the time by the chronometer is greater or less, either the rate of the chronometer had been imperfectly determined, or some circumstance has occurred since its adjustment, to derange the regularity of its movements. For further information on this subject, see TIMEKEEPER.

SECT. II. *To find the difference of Longitude by Celestial Observations.*

The time given by a chronometer, however admirably the instrument may be executed, and however accurate its movements may have been found by previous trial, never can be trusted to with the same degree of confidence as the time deduced from celestial observations made with good instruments. The latter may, no doubt, be incorrect, from various causes; but the errors to which it is liable are known, and appreciable in their extent; whereas the indications of a chronometer, unless they are confirmed by two other time-pieces of at least equal goodness and authority, must always be taken upon trust. Hence the determination of the longitude by celestial observation, has always been regarded as a problem of primary importance to navigation.

The moon being, on account of her vicinity to the earth, of all the heavenly bodies the most rapid in her angular motions, it was soon perceived that the calculation of her position at certain intervals, for a given meridian, would afford the means of ascertaining, by observation, the difference in point of time, between that meridian and any other, where her position was observed to be the same. This method of finding the difference of longitude between two places, was accordingly recommended by various writers so early as the beginning of the 16th century; but the imperfect state of the lunar theory at that period, as well as the rude nature of the instruments which were then used at sea, effectually prevented any advantages resulting to navigation from a proposal, which has since contributed so essentially to its advancement.

For determining the moon's position, the method which has been found to answer best, is that of computing her true distance from the sun, or some remarkable stars lying nearly in the plane of her orbit, with regard to which her angular motion at the time is the most rapid. The stars which have been selected by the British astronomers for this purpose, as points of reference in the heavens, are the following: α Arietis, Aldebaran, Pollux, Regulus, Spica Virginis, Antares, Altair, or α Aquilæ, Fomalhaut, and α Pegasi, or Markab. The moon's distance from the sun, or some one of these stars, is calculated for every 3 hours of apparent time at Greenwich, and inserted in the Nautical Almanack in the 8th, 9th, 10th, and 11th pages of each month; so that the time being known at at any other place where the moon is observed to have the same distance, the means are thus obtained of finding the difference of time between the two meridians, when the same phenomenon takes place at each. Hence their difference of longitude may be computed, by reducing the difference of time to degrees, to be reckoned *east* or *west*, according as the apparent time of the place of observation is greater or less than the time of Greenwich. When the moon's distance is intermediate between two of the distances given in the Nautical Almanack, the instant of time corresponding to it must be calculated, by taking a proportional part for the excess above the next lowest, when the distance is increasing, or for its defect when the distance is decreasing, as illustrated in similar cases under Chap. II. Sect. II.

In order to find the true distance of the moon from the sun or a star, at any particular instant of time, the apparent distance obtained by observation, must undergo certain corrections to divest it of the effects of parallax and refraction, and thus reduce it to what it would be if observed at the centre of the earth. For this purpose the altitude of the moon, and that of the sun or star, must be taken at the same instant when the distance is measured; or if that be impracticable, the time must be accurately observed by means of a good watch, previously regulated to the noon of the place of observation, from which the altitudes of the two bodies may be computed by the method explained in Chap. IV. Sect. II. At any rate, the distance of the moon from the sun or star being the quantity on which the calculation of the Greenwich time chiefly depends, should always be measured with a good Sextant or Circle, well adjusted before the time of observation; and the ship's time, whether inferred from the sun's altitude, taken at the same time with the moon's distance, or some hours before or after, should also be observed with the most scrupulous care. Having given this general view of the method of finding the longitude by lunar distance, we shall describe a little more particularly both the manner of taking the necessary observations, and of calculating from these, after they have been duly corrected, the true distance. In the calculation, we shall employ none of the auxiliary tables which have been furnished with so much profusion to the practical seaman, with the design of simplifying his labours: being persuaded that these Tables have been multiplied to an extent which has defeated their professed object, by involving the subject in a kind of technical obscurity, which is no less forbidding to the more expert, than to the less skillful calculater.

The apparent time of the ship being as essential to the determination of the longitude, as that of Greenwich inferred from the lunar distance, the state of the watch should be ascertained, if the weather permit, by calculating the horary angle from observations of the sun's altitude, taken according to the directions laid down in Chap. IV. Sect. I. either in the morning or evening of the day on which it is proposed to observe the moon's distance from the sun or star; and if the ship should alter her longitude from the time of observing the sun's altitude for computing the horary angle to the time of observing the distance for finding the time at Greenwich, a corresponding correction must be made for the difference of longitude. The apparent time of the ship being thus known by the watch, at the instant of observing the moon's distance from the sun or star, the altitudes of both may be deduced from the horary angle, if the haziness of the horizon should render it impossible to ascertain them by actual observation; but in all cases, where the altitudes can be taken at the instant of measuring the distance, it would be highly improper to neglect to do so, both as affording a check on the going of the watch, and an additional security for the correctness of the horary angle previously calculated.

When the several observations can be made under the most favourable circumstances, four persons should be employed. The most experienced observer should measure the distance of the moon from the sun, when the two luminaries are sufficiently near each other for the purpose, by bringing the reflected image of the latter in contact with the former. In doing this, the plane of the Sextant or Circle should be held in the same line with the objects; and the observer preserving it steadily in that position, should endeavour, by a gentle libration of the instrument, to cause the edge of the reflected image of the sun to glide in contact with the actual disc of the moon seen directly through the unsilvered part of the horizon-glass, until, by means of the adjusting screw, he has satisfactorily completed the observation. When the moon is to the eastward of the sun, it is scarcely necessary to remark, that the instrument must be held with its face upwards, but when the moon is to the westward of the sun, with its face downwards. Two other observers, furnished with good sextants or quadrants, should, at the same time, be engaged in taking the altitudes of the sun and moon, when it is possible to do so, and be both ready to finish their observations at the exact instant the person, who is measuring the distance, gives notice that he has completed his observation. The assistant with the watch should also be prepared to mark the time to a second, and thus all the necessary observations would be completed. The instruments having been examined, and their indications carefully read off with the help of a microscope, another set of observations, with the corresponding time, should be made with as little delay as possible; and so on, until at least four sets have been obtained. The sum of the several distances, and the sums of the altitudes, taken separately, are then to be divided by the number of sets of observations, in order to procure a mean of the whole, and thus guard against the accidental errors to which a single set of observations is liable. The sum of the several times being divided in like manner, the result is to be regarded as the time corresponding to the mean of the observations.

When the distance of the moon from the star is observed, the reflected image of the moon is made to coincide with the star, the face of the instrument being held upwards or downwards, according to the relative position of the two objects, as in the case of the sun and moon. In both cases, however, the observer must be careful to retain, at the instant of completing his observations, the disc of the real object, and the reflected image brought in contact with it, as exactly as possible in the middle between the two wires, placed in the focus of the eyepiece of the telescope; as by this means, if the instrument has been previously adjusted, it will be unnecessary to make any correction for deviation from the axis of the telescope, or line of sight.

All the requisite observations, though they cannot be made at the same instant of time by a single observer, may yet be taken in succession with sufficient accuracy, so as to determine the longitude within the limits necessary, on ordinary occasions, for the safety of navigation, by proceeding in the following manner: Let the altitude of the object which is nearest the meridian be taken first, and the instant of time carefully observed; and then let the altitude of the other be observed in like manner with the corresponding time. These observations being made as expeditiously as is consistent with accuracy, let the distance be next measured, and the instant at which the observation is completed, carefully noted. Lastly, let the altitudes of the two objects be again observed, beginning with the one farthest from the meridian, and let the instant of each observation be marked as before. With these elements, compute the difference upon each altitude, from the time of the first observations to the instant of time at which the distance was observed, and add it to, or subtract it from the first observed altitudes, according as the respective altitude was increasing or decreasing. By this means the altitudes will be adapted to the time at which the distance was observed.

Example. On a particular day, the following observations were made, with the view of finding the altitude of the sun and moon at the instant of time when their distance was observed:

					H.	m.	s.
1st alt. sun .	45°	10′	15″	Time of obs.	5	30	15
1st alt. moon .	39	47	20		5	32	40
Dist. of sun and moon's nearest limbs	102	13	10		5	34	56
2d alt. moon	40	42	15		5	36	40
2d alt. sun .	43	51	10		5	38	42

What were the altitudes of the sun and moon at the time when the distance was observed?

1st. alt. sun	45°	10′	15″	Time	5 h.	30 m.	15 s.
2d alt. sun	43	51	10		5	38	42
Diff. of Alt.	1	19	5	Diff.		8	27

Time of obs. distance of the sun and moon,	5 h.	34 m.	56 s.
1st alt. sun	5	30	15
Difference		4	41

Hence 8 m. 27 s. : 4 m. 41 s. = 1° 19′ 5″ : 43′ 50″

Alt. sun. at time of 1st obs. . .	45°	10′	15″
Change of alt. subtractive . .		43	50
Alt. sun at time distance was observed	44	26	25

1st alt. moon	39°	47′	20″	Time	5 h.	32 m.	40 s.
2d alt. moon	40	42	15		5	36	40
Diff. of alt.		54	55	Diff.		4	0

Time of obs. distance sun and moon	5 h.	34 m.	56 s.
1st alt. moon . .	5	32	40
Difference		2	16

Hence 4 m. : 2 m. 16 s. = 54′ 55″ : 31′ 7″.

Alt. moon at time of 1st obs. .	39°	47′	20″
Change of alt. additive . .		31	7
Alt. moon at time dist. was observed	40	18	27

Hence the elements thus obtained for calculating the longitude, are the sun's altitude 44° 26′ 25″, moon's altitude 40° 18′ 27″, distance of nearest limbs of sun and moon 102° 13′ 10″, and the time common to all the observations, being the time at which the distance was measured, 5 h. 34 m. 56 s. The horary angle deducible from the sun's altitude, will form, as we already observed, a check upon the time given by the watch, when the apparent time has not been obtained in a satisfactory manner from observations of the sun's altitude the preceding day; but an allowance for the change of longitude must in all cases, be made before the times are compared with each other.

When the longitude is to be determined by the distance of the moon from a star, the apparent time of the ship should be deduced, if possible, by observations of the sun's altitude, taken either on the afternoon before observing the distance, or on the following morning; and the altitudes should be computed by means of the horary angle, reduced to what it would have been at the instant of observing the distance, by making a suitable correction for the difference of longitude. The second method, which we have given in Chap. IV. Sect. II. for computing the altitude of a celestial object from the latitude, its declination, and the horary angle, will increase in a very small degree the trouble of finding the moon's true distance from the star by thus calculating, instead of observing the altitudes of the two bodies.

Having described, with sufficient minuteness, the manner of obtaining by observation the necessary quantities for calculating the moon's true distance from the sun or a star, we shall now proceed to explain the methods of performing the calculation. These methods may be greatly varied; but we shall confine ourselves to two, one of which has been proposed by Borda, and the other by Delambre. Both of them are exceedingly simple, and, what is no small recommendation, neither of them requires any auxiliary tables.

The data from which the true distance is to be inferred are, the apparent altitudes of the centres of the two objects, their true altitudes, and the observed or apparent distance of their centres. Let HZO, Plate CCCCIV. Fig. 31, represent the meridian of the place of observation; HO the horizon, and Z. the zenith; also, let S and M be the apparent positions of the sun and moon respectively. Then BS being the apparent altitude of the sun, ZS will be the apparent zenith distance; in like manner, AM being the apparent altitude of the moon, ZM will be her apparent zenith distance; and MS will be the apparent or observed distance. The sun's parallax being at all altitudes less than the correction for refraction, his true zenith distance Zs will always be less than his apparent zenith distance; while, on the other hand, the moons parallax in altitude being at all altitudes greater than the correction for refraction, her true zenith distance Zm will always be greater than her apparent zenith distance. Hence, the true distance to be determined is ms. From these considerations, it is easy to perceive, that the angle at Z, being common to the two triangles MZS and mZs, that angle must first be computed in the former triangle, the three sides of which are given, viz. MZ, SZ, and MS, and afterwards employed with the two sides mZ and sZ, of the triangle mZs, to calculate the true distance ms.

Method of Borda.

Write under one another the apparent distance of the centres of the two objects, the apparent altitude of the sun or star, and the apparent altitude of the moon; and, having added them together, take half their sum. Find the difference of the half sum, and the apparent distance, and write under it the true altitude of the sun or star, and the true altitude of the moon. Add together the true altitudes, and take half their sum. After these preliminary arrangements, search in the Tables for the arithmetical complements of the logarithmic cosines of the apparent altitudes; the logarithmic cosine of the half sum of these altitudes, and the apparent distance; the logarithmic cosine of the half difference; and the logarithmic cosines of the true altitudes. Add together these different logarithms, and from half their sum subtract the logarithmic cosine of half the sum of the true altitudes, and the remainder will be the logarithmic sine of an auxiliary angle. Place the logarithmic cosine of this auxiliary angle under the logarithmic cosine of the half sum of the true altitudes, and their sum, rejecting 10 from the index, will be the logarithmic sine of half the true distance. The result, therefore, being doubled, will be the distance, freed from the effects of parallax and refraction, or the true distance from which the time at Greenwich is to be deduced by help of the Nautical Almanack.

Example.—January 10, 1821, being in latitude 26° 50′ N. long. 88° 10′ W. by account, at 3h. 35m. 10s. P. M. by the watch, four observations of the distance of the sun from the moon, and an equal number of simultaneous observations of their altitudes, were taken, from which it appeared, that the mean distance of the nearest limbs, at the mean of the times stated, was 87° 20′ 35″, the mean altitude of the sun's lower limb 16° 10′ 20″, and that of the moon's lower limb 60° 35′ 15″. What was the longitude of the place of observation, the eye of each observer having been 24 feet above the surface of the sea?

The difference of longitude by account reduced to time, is 5h. 52m. 40s. and the time by the watch being 3h. 35m. 10s. the approximated time at Greenwich is 9h. 27m. 50s. The sun's semidiameter for the given day is, by the Nautical Almanack, 16′ 17″, and the moon's 16′ 6″. To the latter must be added 14″, from Table XXXII. Astronomy, for the augmentation on account of altitude, which brings it to 16′ 20″. These two semidiameters must be added to the respective altitudes, after they are corrected for dip, to obtain the apparent altitudes of the centres of the sun and moon, and also to the apparent distance of the limbs, to reduce it to the apparent distance of the centres.

Observed distance of the nearest limbs of sun & moon	87° 20′ 35″
Semidiameter of the sun . . .	+ 16 17
Semidiameter of the moon . . .	+ 16 20
Apparent distance of centres of sun and moon .	87 53 12

The sun's parallax from Table XLV. Astronomy, for the altitude 16° 26′ is 8″. The moon's equatorial parallax taken from the Nautical Almanack, and reduced to the computed time, is 59′ 7″, from which, if great precision is aimed at, let 3″ be subtracted for the latitude of the place of observation. This correction, which may for the most part be omitted, is found in Table XXX. Astronomy, and reduces the moon's horizontal parallax to 59′ 4″. The parallax for the observed altitude is obtained by multiplying 59′ 4″, reduced to seconds by the natural cosine of the altitude, viz. .487, which brings it to 1726″, or 28′ 46″. From these preliminary quantities the altitudes are computed as follows:

Obs. alt. of sun's lower limb .		16° 10′ 20″
Dip for 24 f.		4 48
		16 5 32
Semidiameter . . .		+ 16 17
Apparent altitude of sun's centre		16 21 49
Refraction	− 3′ 14″	− 3 6
Parallax	+ 8	
True altitude of sun's centre .		16 18 43

Obs. alt. of moon's lower limb		60° 35′ 15″
Dip for 24 f.		4 48
		60 30 27
Semidiameter		+ 16 20
Apparent altitude of moon's centre		60 46 47
Refraction	— 0′ 32″	28 14
Parallax	+ 28 46	
True altitude of moon's centre		61 15 1

App. dist of sun and moon	87°	53′	12″		
App. alt. of sun	16	21	49	Ar. com. cosine	.0179581
App. alt. of moon	60	46	47	Ar. com. cosine	.3114301
Sum	165	1	48		
½ sum	82	30	54	Cosine	9.1148331
Diff. app. dist. and ½ sum	5	22	18	Cosine	9.9980885
True alt. of sun	16	18	43	Cosine	9.9821567
True alt. of moon	61	15	1	Cosine	9.6821311
Sum true alts.	77	33	44	Sum	39.1065976
				½ sum	19.5532988
½ sum true alts.	38°	46′	52″	Cosine	9.8918409
Auxiliary angle	27	17	54	Sine	9.6614579
Auxiliary angle	27	17	54	Cosine } sum.	9.9487212
½ sum true alt.	38	46	52	Cosine } sum.	9.8918409
½ *true distance*	43	50	47	Sine	9.8405621
			2		
TRUE DISTANCE	87	41	34		

The two lunar distances in the Nautical Almanack, between which the computed distance is found for the given day, are 87° 14′ 51″, and 88° 52′ 36″, the former being the distance of the moon from the sun at 9 o'clock, and the latter the distance at midnight. The difference between these distances is 1° 37′ 45″, being the change of distance in 3 hours. Also, the difference between the first distance and the computed distance is 0° 26′ 43″, so that we have,

1° 37′ 45″ : 26′ 43″=3h. 49m. 12s.=time elap. from 9 o'clock.

The time at Greenwich, when the observations were made, being thus ascertained to be 9h. 49m. 12s. it only remains to determine the time at the place of observation, by the method explained in Chap. IV. Sect. I.

To find the Time at the place of Observation.

True alt. sun's centre	16°	18′	43″		
Latitude	26	50	0	Ar. comp. cosine	.0495777
Polar distance	111	54	38	Ar. comp. sine	.0325609
Sum	155	3	21		
½ sum	77	31	40	Cosine	9.3342145
Dif. ½ sum and alt. ⊙	61	12	57	Sine	9 9427024
				Sum	19.3590555
½ Horary angle	28	33	43	Sine	9.6795277
			2		
Horary angle	57	7	26	which, red. to time, is 3h. 48m. 29s.	

Time at Greenwich	9h.	49m.	12s.
Time at the ship	3	48	29
Difference of time	6	0	43

which, reduced to degrees, &c. gives 90° 10′ 45″ for the longitude of the ship *westerly*, because the ship's time is behind that of Greenwich.

Method of Delambre.

One of the methods which Delambre has proposed for calculating the true distance of the moon from the sun or a star, by means of the apparent distance, and the altitudes of the two bodies, may be regarded as a simplification of the method of Borda, to which it has a considerable similarity. It consists in adding to the sum of the first six logarithms employed in Borda's method, the logarithm of 2, viz. .301030, and then finding the number, in the table of the logarithms of numbers, corresponding to the sum, after rejecting the tens from the index. This number being found, the natural cosine of the sum of the true altitudes is to be subtracted from it; the difference is the natural cosine of the true distance. If the natural cosine of the sum of the altitudes be the greater, the difference is still to be taken as the natural cosine of the true distance, only in this case the corresponding arch is the supplement of the arch found in the tables. We shall illustrate this method, by solving, by means of it, the last example.

Sum of first six logs. in Borda's method	39.1065976
Logarithm of 2	.3010300
Log. of .2556393	1.4076276
.2153792=nat. cos. sum of true alts.	77° 33′ 44″
.0402601=nat. cos. TRUE DISTANCE	87 41 34

When the moon's distance from a star is observed, and the altitudes are deduced by means of the horary angle corresponding to the time of observation, the apparent altitudes are obtained by reversing the operations for finding the true from the apparent altitudes. Hence, the true altitude of the star must be augmented by the corresponding refraction; while that of the moon must be diminished by the excess of her parallax in altitude above the refraction for that altitude. If the altitudes are very small, it may be necessary to take the refraction and parallax in altitude corresponding to the altitude thus found, and apply them to the true altitudes as before. The operation for computing the true distance is then performed precisely in the same manner as in the case of the sun.

EXAMPLE.—Feb. 16, 1821, being in lat. 19° 36′ S. long. 73° 20′ E. by account, at 8h. 37m. 20s. P. M. by a watch, which had been adjusted to apparent time a little before sunset, the distance of the moon's nearest limb from Aldebaran, was observed to be 76° 40′ 20″; what was the longitude of the place of observation, the ship's true course and distance made good, since the time the watch was adjusted, having been E. S. E. 15 miles?

With the course and distance since the watch was adjusted, the difference of longitude is found to be 16 miles, which, reduced to time, is 1m. 4s.

Time at ship by the watch	8h.	37m.	20s.
Cor. for change of long.		1	4
APP. TIME at ship	8	38	24
Estimated longitude in time	4	53	20
Estimated time at Greenwich	3	45	4

The moon's semidiameter, adapted to the estimated time of Greenwich, is 14′ 56″, so that the apparent distance of the star from the moon's centre is 76° 55′ 16″; also, the moon's declination, adapted in like manner, is 15° 21′ N. and hence, her polar distance, reckoned from the elevated pole, is 105° 21′.

To find the Moon's Altitude.

App. time of ship	8h.	38m.	24s.
Sun's right ascension for estimated time	21	59	39
Right ascension *of meridian*	6	38	3
Moon's right ascension corrected	9	46	16
Moon's hor. angle E. of merid.	=3	8	13

which, reduced to degrees, &c. is 47° 3′ 15″.

Latitude	19° 36′	Cosine	9.9740774
Moon's pol. dist.	105 21	Sine	9.9842242
Moon's hor. angle	47 3 15″	Vers. sine	9 5033730
Sum, rejecting 30 = Log. of	.289517		1.4616746
Nat. cos. (P. dist.—co-lat.) 34° 57′	.819652		

.530135=Nat. sine of 32° 0′ 52″=true altitude of the moon.

To find the Altitude of Aldebaran.

The R. A. of Aldebaran, taken from the Naut. Alm. and adapted to the time, is 4 h. 25 m. 39 s. and his Pol. dist. 106° 8′ 29″.

R. A. of merid. found above	6 h.	38 m.	3 s.
R. A. of Aldebaran . .	4	25	39
Hor. angle of Aldeb. W. of merid.	2	12	24

which, reduced to degrees, &c. is 33° 8′.

Latitude .	19°	36′	0″	Cosine	9.9740774
Pol. dist. .	106	8	29	Sine	9.9825329
Hor. angle of Ald.	33	8	0	Vers. sine	9.2111182
Sum rejecting 30 = Log. of .				.147136	1.1677285
Nat. cos. (P. dis.—co. lat. = nat. cos. 35° 44′ 29″				.811662	
				.664526 = nat. sine 41°38′4″	

= true alt. of Aldebaran.

Having found the true altitudes, the apparent altitudes must be deduced from them, by subtracting from the Moon's true altitude the difference of the refraction, and parallax in altitude, and adding to the Star's true altitude the corresponding refraction. The Moon's hor. parallax, corrected for the app. time at Greenwich, is 54′ 46″; which, multiplied by the nat. cosine of the altitude, gives 46′ 26″ for the parallax in altitude.

Moon's true alt. . .				32°	0′	52″
Refraction	+	1′	31″	—	44	55
Parallax in alt.	—	46	26			
Moon's app. alt. . . .				31	15	57
True alt. of Aldeb. . . .				41°	38′	4″
Refraction				+	1	4
App. alt. Aldeb. . . .				41	39	8

To find the true distance.

App. dist. Moon and Star	76°	55′	16″		
App. alt. Star .	41	39	8	Arith comp. cos.	.1265674
App. alt. Moon .	31	15	57	Arith. comp. cos.	.0681515
Sum . .	149	50	21		
½ Sum . .	74	55	10	Cosine .	9.4153687
Diff of ½ sum and app. dist.	2	0	6	Cosine .	9.9997350
True alt. Star .	41	38	4	Cosine .	9.8735524
True alt. Moon .	32	0	52	Cosine .	9.9283520
Sum of true alts. .	73	38	56	Log. 2. .	.3010300
Sum rejecting 40 = Log. of	.5161275			. . .	1.7127570
	.2815228 = N.cos. sum true alts. 73° 38′ 56″				
	.2346047 = N.cos. True Dist. 76 25 54				

The two lunar distances in the Naut. Alm. between which the calculated distance is found for the given day, are 76° 13′ 10″, and 77° 43′ 7″, the former being the distance of the Moon from Aldebaran at III. and the latter at VI. o'clock. The difference between these distances is 1° 29′ 57″, being the change of distance in three hours: also the difference between the first distance and the computed distance is 12′ 44″. Hence we have

1° 29′ 57″ : 12′ 44″ = 3 h. : 25 m. 29 s. = time elapsed from III o'clock.

App. time at the ship . .	8 h.	37 m.	20 s.
App. time at Greenwich .	3	25	29
Diff. of time . . .	5	11	51

which, reduced to degrees, &c. is 77° 57′ 45″, being the longitude of the ship *east* from Greenwich, because the ship's time exceeds that of Greenwich.

These computations for divesting the observed distance of the effects of parallax and refraction being necessarily attended with a considerable degree of labour, various attempts have been made to simplify them by means of auxiliary tables; but, after all, it may be justly questioned, how far any of the methods which have been proposed for this purpose are to be preferred to the method of Delambre. The method of Dunthorn, as it was afterwards improved by Dr. Maskelyne, seems the most expeditious, (see *Requisite Tables*, and the *Naut. Almanack* for 1767;) but it requires the assistance of a Table, entitled, *Logarithmic Differences*, and with this aid it employs only two logarithms less than the method of Delambre, while it is much less simple in appearance. See La Lande *Astron.* tom. iii. p. 651; Biot *Astron.* tom. iii.

CHAP. VI.

OF THE VARIATION OF THE COMPASS.

As we propose to consider this subject in the fullest manner, under the article VARIATION, it is announced in this place merely as a branch of Nautical Astronomy.

The deviation of the magnetic from the true meridian, is termed the *Variation*, and is denominated *East* or *West*. according as the north end of the compass points to the east or west of the true north. The determination of the variation, therefore, consists in finding the difference between the true and magnetic bearing of a heavenly object, at some particular instant of time; the former being ascertained by calculation, and the latter by means of a compass duly fitted up for the purpose. See VARIATION.

OF A SEA-JOURNAL.

Having explained, in Part I. of this article, the method of finding a ship's course and distance from one place to another, by the various kinds of sailing, and illustrated, by numerous examples, the means which are afforded by the log-line and compass of determining the ship's position, from time to time, in the course of her voyage; and having described, in Part II. the most convenient methods of ascertaining the ship's place by celestial observation, we shall devote this chapter to a brief account of the method of keeping a Journal of the different occurrences and proceedings which may be supposed to take place at sea.

The principal design of a journal at sea being to preserve a record of the various circumstances by which the ship's place is to be known, whether by dead reckoning or celestial observation, every thing connected with the ship's course and distance, and the determination of the latitude and longitude, must be carefully registered, in a form best adapted for discovering at any time the ship's position.

The journal may be greatly varied in form; but it should always contain, arranged in appropriate columns, the ship's rate of sailing for every hour, or two hours at most; the winds; the courses; the lee-way and variation; together with an abstract from these of the course and distance made good, from noon to noon; the difference of latitude and departure; the latitude and longitude in by dead reckoning; and the bearing and distance of the intended port. To these should be added, as circumstances permit, the latitude and longitude of the ship, inferred from celestial observation, with a short statement of the manner in which they were obtained. A column of considerable width should also be allotted for recording the ordinary occurrences on board of ship, such as the state of the weather; the employment of the crew; the alteration of the sails; the ships fallen in with at sea; the appearance of lands when visible; the indications of currents; the soundings and temperature of the ocean, &c.; each event being recorded as exactly as possible in its proper order of time.

TABLE I.

Traverse Table to Points and Quarters of the Compass.

For ¼ Point.											
Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	1.0	0.0	61	60.9	3.0	121	120.9	5.9	181	180.8	8.9
2	2.0	0.1	62	61.9	3.0	122	121.9	6.0	182	181.8	8.9
3	3.0	0.1	63	62.9	3.1	123	122.9	6.0	183	182.8	9.0
4	4.0	0.2	64	63.9	3.1	124	123.9	6.1	184	183.8	9.0
5	5.0	0.2	65	64.9	3.2	125	124.8	6.1	185	184.8	9.1
6	6.0	0.3	66	65.9	3.2	126	125.8	6.2	186	185.8	9.1
7	7.0	0.3	67	66.9	3.3	127	126.8	6.2	187	186.8	9.2
8	8.0	0.4	68	67.9	3.3	128	127.8	6.3	188	187.8	9.2
9	9.0	0.4	69	68.9	3.4	129	128.8	6.3	189	188.8	9.3
10	10.0	0.5	70	69.9	3.4	130	129.8	6.4	190	189.8	9.3
11	11.0	0.5	71	70.9	3.5	131	130.8	6.4	191	190.8	9.4
12	12.0	0.6	72	71.9	3.5	132	131.8	6.5	192	191.8	9.4
13	13.0	0.6	73	72.9	3.6	133	132.8	6.5	193	192.8	9.5
14	14.0	0.7	74	73.9	3.6	134	133.8	6.6	194	193.8	9.5
15	15.0	0.7	75	74.9	3.7	135	134.8	6.6	195	194.8	9.6
16	16.0	0.8	76	75.9	3.7	136	135.8	6.7	196	195.8	9.6
17	17.0	0.8	77	76.9	3.8	137	136.8	6.7	197	196.8	9.7
18	18.0	0.9	78	77.9	3.8	138	137.8	6.8	198	197.8	9.7
19	19.0	0.9	79	78.9	3.9	139	138.8	6.8	199	198.8	9.8
20	20.0	1.0	80	79.9	3.9	140	139.8	6.9	200	199.8	9.8
21	21.0	1.0	81	80.9	4.0	141	140.8	6.9	201	200.8	9.9
22	22.0	1.1	82	81.9	4.0	142	141.8	7.0	202	201.8	9.9
23	23.0	1.1	83	82.9	4.1	143	142.8	7.0	203	202.8	10.0
24	24.0	1.2	84	83.9	4.1	144	143.8	7.1	204	203.8	10.0
25	25.0	1.2	85	84.9	4.2	145	144.8	7.1	205	204.8	10.1
26	26.0	1.3	86	85.9	4.2	146	145.8	7.2	206	205.8	10.1
27	27.0	1.3	87	86.9	4.3	147	146.8	7.2	207	206.8	10.2
28	28.0	1.4	88	87.9	4.3	148	147.8	7.3	208	207.7	10.2
29	29.0	1.4	89	88.9	4.4	149	148.8	7.3	209	208.7	10.3
30	30.0	1.5	90	89.9	4.4	150	149.8	7.4	210	209.7	10.3
31	31.0	1.5	91	90.9	4.5	151	150.8	7.4	211	210.7	10.4
32	32.0	1.6	92	91.9	4.5	152	151.8	7.5	212	211.7	10.4
33	33.0	1.6	93	92.9	4.6	153	152.8	7.5	213	212.7	10.5
34	34.0	1.7	94	93.9	4.	154	153.8	7.6	214	213.7	10.5
35	35.0	1.7	95	94.9	4.7	155	154.8	7.6	215	214.7	10.5
36	36.0	1.8	96	95.9	4.7	156	155.8	7.7	216	215.7	10.6
37	37.0	1.8	97	96.9	4.8	157	156.8	7.7	217	216.7	10.6
38	38.0	1.9	98	97.9	4.8	158	157.8	7.8	218	217.7	10.7
39	39.0	1.9	99	98.9	4.9	159	158.8	7.8	219	218.7	10.7
40	40.0	2.0	100	99.9	4.9	160	159.8	7.9	220	219.7	10.8
41	41.0	2.0	101	100.9	5.0	161	160.8	7.9	221	220.7	10.8
42	41.9	2.1	102	101.9	5.0	162	161.8	7.9	222	221.7	10.9
43	42.9	2.1	103	102.9	5.1	163	162.8	8.0	223	222.7	10.9
44	43.9	2.2	104	103.9	5.1	164	163.8	8.0	224	223.7	11.0
45	44.9	2.2	105	104.9	5.2	165	164.8	8.1	225	224.7	11.0
46	45.9	2.3	106	105.9	5.2	166	165.8	8.1	226	225.7	11.1
47	46.9	2.3	107	106.9	5.3	167	166.8	8.2	227	226.7	11.1
48	47.9	2.4	108	107.9	5.3	168	167.8	8.2	22	227.7	11.2
49	48.9	2.4	109	108.9	5.4	169	168.8	8.3	229	228.7	11.2
50	49.9	2.5	110	109.9	5.4	170	169.8	8.3	230	229.7	11.3
51	50.9	2.5	111	110.9	5.5	171	170.8	8.4	231	230.7	11.3
52	51.9	2.6	112	111.9	5.5	172	171.8	8.4	232	231.7	11.4
53	52.9	2.6	113	112.9	5.5	173	172.8	8.5	233	232.7	11.4
54	53.9	2.6	114	113.9	5.6	174	173.8	8.5	234	233.7	11.5
55	54.9	2.7	115	114.9	5.6	175	174.8	8.6	235	234.7	11.5
56	55.9	2.7	116	115.9	5.7	176	175.8	8.6	236	235.7	11.6
57	56.9	2.8	117	116.9	5.7	177	176.8	8.7	237	236.7	11.6
58	57.9	2.8	118	117.9	5.8	178	177.8	8.7	238	237.7	11.7
59	58.9	2.9	119	118.9	5.8	179	178.8	8.8	239	238.7	11.7
60	59.9	2.9	120	119.9	5.9	180	179.8	8.8	240	239.7	11.8
Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat
For 7¾ Points.											

For ½ Point.											
Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat	Dep.	Dist.	D. Lat.	Dep.
1	1.0	0.1	61	60.7	6.0	121	120.4	11.9	181	180.1	17.7
2	2.0	0.2	62	61.7	6.1	122	121.4	12.0	182	181.1	17.8
3	3.0	0.3	63	62.7	6.2	123	122.4	12.1	183	182.1	17.9
4	4.0	0.4	64	63.7	6.3	124	123.4	12.2	184	183.1	18.0
5	5.0	0.5	65	64.7	6.4	125	124.4	12.3	185	184.1	18.1
6	6.0	0.6	66	65.7	6.5	126	125.4	12.4	186	185.1	18.2
7	7.0	0.7	67	66.7	6.6	127	126.4	12.4	187	186.1	18.3
8	8.0	0.8	68	67.7	6.7	128	127.4	12.5	188	187.1	18.4
9	9.0	0.9	69	68.7	6.8	129	128.4	12.6	189	188.1	18.5
10	10.0	1.0	70	69.7	6.9	130	129.4	12.7	190	189.1	18.6
11	10.9	1.1	71	70.7	7.0	131	130.4	12.8	191	190.1	18.7
12	11.9	1.2	72	71.7	7.1	132	131.4	12.9	192	191.1	18.8
13	12.9	1.3	73	72.6	7.2	133	132.4	13.0	193	192.1	18.9
14	13.9	1.4	74	73.6	7.3	134	133.4	13.1	194	193.1	19.0
15	14.9	1.5	75	74.6	7.4	135	134.3	13.2	195	194.1	19.1
16	15.9	1.6	76	75.6	7.4	136	135.3	13.3	196	195.1	19.2
17	16.9	1.7	77	76.6	7.5	137	136.3	13.4	197	196.1	19.3
18	17.9	1.8	78	77.6	7.6	138	137.3	13.5	198	197.0	19.4
19	18.9	1.9	79	78.6	7.7	139	138.3	13.6	199	198.0	19.5
20	19.9	2.0	80	79.6	7.8	140	139.3	13.7	200	199.0	19.6
21	20.9	2.1	81	80.6	7.9	141	140.3	13.8	201	200.0	19.7
22	21.9	2.2	82	81.6	8.0	142	141.3	13.9	202	201.0	19.8
23	22.9	2.3	83	82.6	8.1	143	142.3	14.0	203	202.0	19.9
24	23.9	2.4	84	83.6	8.2	144	143.3	14.1	204	203.0	20.0
25	24.9	2.5	85	84.6	8.3	145	144.3	14.2	205	204.0	20.1
26	25.9	2.5	86	85.6	8.4	146	145.3	14.3	206	205.0	20.2
27	26.9	2.6	87	86.6	8.5	147	146.3	14.4	207	206.0	20.3
28	27.9	2.7	88	87.6	8.6	148	147.3	14.5	208	207.0	20.4
29	28.9	2.8	89	88.6	8.7	149	148.3	14.6	209	208.0	20.5
30	29.9	2.9	90	89.6	8.8	150	149.3	14.7	210	209.0	20.6
31	30.9	3.0	91	90.6	8.9	151	150.3	14.8	211	210.0	20.7
32	31.8	3.1	92	91.6	9.0	152	151.3	14.9	212	211.0	20.8
33	32.8	3.2	93	92.6	9.1	153	152.3	15.0	213	212.0	20.9
34	33.8	3.3	94	93.5	9.2	154	153.3	15.1	214	213.0	21.0
35	34.8	3.4	95	94.5	9.3	155	154.3	15.2	215	214.0	21.1
36	35.8	3.5	96	95.5	9.4	156	155.2	15.3	216	215.0	21.2
37	36.8	3.6	97	96.5	9.5	157	156.2	15.4	217	216.0	21.3
38	37.8	3.7	98	97.5	9.6	158	157.2	15.5	218	217.0	21.4
39	38.8	3.8	99	98.5	9.7	159	158.2	15.6	219	217.9	21.5
40	39.8	3.9	100	99.5	9.8	160	159.2	15.7	220	218.9	21.6
41	40.8	4.0	101	100.5	9.9	161	160.2	15.8	221	219.9	21.7
42	41.8	4.1	102	101.5	10.0	162	161.2	15.9	222	220.9	21.8
43	42.8	4.2	103	102.5	10.1	163	162.2	16.0	223	221.9	21.9
44	43.8	4.3	104	103.5	10.2	164	163.2	16.1	224	222	22.0
45	44.8	4.4	105	104.5	10.3	165	164.2	16.2	25	223.9	22.1
46	45.8	4.5	106	105.5	10.4	166	165.2	16.3	226	224.9	22.2
47	46.8	4.6	107	106.5	10.5	167	166.2	16.4	227	225.9	22.2
48	47.8	4.7	108	107.5	10.6	168	167.2	16.5	228	226.9	22.3
49	48.8	4.8	109	108.5	10.7	169	168	16.6	229	227.9	22.4
50	49.8	4.9	110	109.5	10.8	170	169.2	16.7	230	228.9	22.5
51	50.8	5.0	111	110.5	10.9	171	170.2	16.8	231	229.9	22.6
52	51.7	5.1	112	111.5	11.0	172	171.2	16.9	232	230.9	22.7
53	52.7	5.2	113	112.5	11.1	173	172.2	17.0	233	231.9	22.8
54	53.7	5.3	114	113.5	11.2	174	173.2	17.1	234	232.9	22.9
55	54.7	5.4	115	114.4	11.3	175	174.2	17.2	235	233.9	23.0
56	55.7	5.5	116	115.4	11.4	176	175.2	17.3	236	234.9	23.1
57	56.7	5.6	117	116.4	11.5	177	176.1	17.3	237	235.9	23.2
58	57.7	5.7	118	117.4	11.6	178	177.1	17.4	238	236.9	23.3
59	58.7	5.8	119	118.4	11.7	179	178.1	17.5	239	237.8	23.4
60	59.7	5.9	120	119.4	11.8	180	179.1	17.6	240	238.8	23.5
Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat
For 7½ Points.											

TABLE I.—*Continued.*

Traverse Table to Points and Quarters of the Compass.

For ¾ Point.											
Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	1.0	0.1	61	60.3	9.0	121	119.7	17.8	181	179.0	26.6
2	2.0	0.3	62	61.3	9.1	122	120.7	17.9	182	180.0	26.7
3	3.0	0.4	63	62.3	9.2	123	121.7	18.0	183	181.0	26.9
4	4.0	0.6	64	63.3	9.4	124	122.7	18.2	184	182.0	27.0
5	4.9	0.7	65	64.3	9.5	125	123.6	18.3	185	183.0	27.1
6	5.9	0.9	66	65.3	9.7	126	124.6	18.5	186	184.0	27.3
7	6.9	1.0	67	66.3	9.8	127	125.6	18.6	187	185.0	27.4
8	7.9	1.2	68	67.3	10.0	128	126.6	18.8	188	186.0	27.6
9	8.9	1.3	69	68.3	10.1	129	127.6	18.9	189	187.0	27.7
10	9.9	1.5	70	69.2	10.3	130	128.6	19.1	190	187.9	27.9
11	10.9	1.6	71	70.2	10.4	131	129.6	19.2	191	188.9	28.0
12	11.9	1.8	72	71.2	10.6	132	130.6	19.4	192	189.9	28.2
13	12.9	1.9	73	72.2	10.7	133	131.6	19.5	193	190.9	28.3
14	13.8	2.1	74	73.2	10.9	134	132.5	19.7	194	191.9	28.5
15	14.8	2.2	75	74.2	11.0	135	133.5	19.8	195	192.9	28.6
16	15.8	2.3	76	75.2	11.2	136	134.5	20.0	196	193.9	28.8
17	16.8	2.5	77	76.2	11.3	137	135.5	20.1	197	194.9	28.9
18	17.8	2.6	78	77.2	11.4	138	136.5	20.2	198	195.9	29.1
19	18.8	2.8	79	78.1	11.6	139	137.5	20.4	199	196.8	29.2
20	19.8	2.9	80	79.1	11.7	140	138.5	20.5	200	197.8	29.3
21	20.8	3.1	81	80.1	11.9	141	139.5	20.7	201	198.8	29.5
22	21.8	3.2	82	81.1	12.0	142	140.5	20.8	202	199.8	29.6
23	22.8	3.4	83	82.1	12.2	143	141.5	21.0	203	200.8	29.8
24	23.7	3.5	84	83.1	12.3	144	142.4	21.1	204	201.8	29.9
25	24.7	3.7	85	84.1	12.5	145	143.4	21.3	205	202.8	30.1
26	25.7	3.8	86	85.1	12.6	146	144.4	21.4	206	203.8	30.2
27	26.7	4.0	87	86.1	12.8	147	145.4	21.6	207	204.8	30.4
28	27.7	4.1	88	87.0	12.9	148	146.4	21.7	208	205.7	30.5
29	28.7	4.3	89	88.0	13.1	149	147.4	21.9	209	206.7	30.7
30	29.7	4.4	90	89.0	13.2	150	148.4	22.0	210	207.7	30.8
31	30.7	4.5	91	90.0	13.4	151	149.4	22.2	211	208.7	31.0
32	31.7	4.7	92	91.0	13.5	152	150.4	22.3	212	209.7	31.1
33	32.6	4.8	93	92.0	13.6	153	151.3	22.4	213	210.7	31.3
34	33.6	5.0	94	93.0	13.8	154	152.3	22.6	214	211.7	31.4
35	34.6	5.1	95	94.0	13.9	155	153.3	22.7	215	212.7	31.5
36	35.6	5.3	96	95.0	14.1	156	154.3	22.9	216	213.7	31.7
37	36.6	5.4	97	96.0	14.2	157	155.3	23.0	217	214.7	31.8
38	37.6	5.6	98	96.9	14.4	158	156.3	23.2	218	215.6	32.0
39	38.6	5.7	99	97.9	14.5	159	157	23.3	219	216.6	32.1
40	39.6	5.9	100	98.9	14.7	160	158.3	23.5	220	217.6	32.3
41	40.6	6.0	101	99.9	14.8	161	159.3	23.6	221	218.6	32.4
42	41.5	6.2	102	100.9	15.0	162	160.2	23.8	222	219.6	32.6
43	42.5	6.3	103	101.9	15.1	163	161.2	23.9	223	220.6	32.7
44	43.5	6.5	104	102.9	15.3	164	162.2	24.1	224	221.6	32.9
45	44.5	6.6	105	103.9	15.4	165	163.2	24.2	225	222.6	33.0
46	45.5	6.7	106	104.9	15.6	166	164.2	24.4	226	223.6	33.2
47	46.5	6.9	107	105.8	15.7	167	165.2	24.5	22	224.5	33.3
48	47.5	7.0	108	106.8	15.8	168	166.2	24.7	228	225.5	33.5
49	48.5	7.2	109	107.8	16.0	169	167.2	24.8	229	226.5	33.6
50	49.5	7.3	110	108.8	16.1	170	168.2	24.9	230	227.5	33.7
51	50.4	7.5	111	109.8	16.3	171	169.1	25.1	231	228.5	33.9
52	51.4	7.6	112	110.8	16.4	172	70	25.2	232	229.5	34.0
53	52.4	7.8	113	111.8	16.6	173	171.1	25.4	233	230.5	34.2
54	53.4	7.9	114	112.8	16.7	174	172.1	25.5	234	231.5	34.3
55	54.4	8.1	115	113.8	16.9	175	173.1	25.7	235	232.5	34.5
56	55.4	6.2	116	114.7	17.0	176	174.1	25.8	236	233.4	34.6
57	56.4	8.4	117	115.7	17.2	177	175.1	26.0	237	234.4	34.8
58	57.4	8.5	118	116.7	17.3	178	176.1	26.1	238	235.4	34.9
59	58.4	8.7	119	117.7	17.5	179	177.1	26.3	239	236.4	35.1
60	59.4	8.8	120	118.7	17.6	180	178.1	26.4	240	237.4	35.2
Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat
For 7¼ Points.											

For 1 Point.											
Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	1.0	0.2	61	59.8	11.9	121	118.7	23.6	181	177.5	35.3
2	2.0	0.4	62	60.8	12.1	122	119.7	23.8	182	178.5	35.5
3	2.9	0.6	63	61.8	12.3	123	120.6	24.0	183	179.5	35.7
4	3.9	0.8	64	62.8	12.5	124	121.6	24.2	184	180.5	35.9
5	4.9	1.0	65	63.8	12.7	125	122.6	24.4	185	181.4	36.1
6	5.9	1.2	66	64.7	12.9	126	123.6	24.6	186	182.4	36.3
7	6.9	1.4	67	65.7	13.1	27	124.6	24.8	187	183.4	36.5
8	7.8	1.6	68	66.7	13.3	128	125.5	25.0	188	184.4	36.5
9	8.8	1.8	69	67.7	13.5	129	126.5	25.2	189	185.4	36.9
10	9.8	2.0	70	68.7	13.7	130	127.5	25.4	190	186.3	37.1
11	10.8	2.1	71	69.6	13.9	131	128.5	25.6	191	187.3	37.3
12	11.8	2.3	72	70.6	14	32	129.5	25.8	192	188.3	37.5
13	12.8	2.5	73	71.6	14.2	133	130.4	25.9	193	189.3	37.7
14	13.7	2.7	74	72.6	14	34	131.4	26.1	194	190.3	37.8
15	14.7	2.9	75	73.6	14.6	135	132.4	26.3	195	191.3	38.0
16	15.7	3.1	76	74.5	14.8	136	133.4	26.5	196	192.2	38.2
17	16.7	3.3	77	75.5	15.0	137	134.4	26.7	197	193.2	38.4
18	17.7	3.5	78	76.5	15.2	138	135.3	26.9	198	194.2	38.6
19	18.6	3.7	79	77.5	15.4	39	136.3	27.1	199	195.2	38.8
20	19.6	3.9	80	78.5	15.6	140	137.3	27.3	200	196.2	39.0
21	20.6	4.1	81	79.4	15.8	141	138.3	27.5	201	197.1	39.2
22	21.6	4.3	82	80.4	16.0	142	139.3	27.7	20	198.1	39.4
23	22.6	4.5	83	81.4	16.2	143	140.3	7.9	203	199.1	39.6
24	23.5	4.7	84	82.4	16.4	144	141.2	28.1	204	200.1	39.8
25	24.5	4.9	85	83.4	16.6	145	142.2	28.3	205	201.1	40.0
26	25.5	5.1	86	84.3	16.8	146	143.2	28.5	206	202.0	40.2
27	26.5	5.3	87	85.3	17.0	147	144.2	28.7	207	203.0	40.4
28	27.5	5.5	88	86.3	17.2	148	145.2	28.9	208	204.0	40.6
29	28.4	5.7	89	87.3	17.4	149	146.1	29.1	209	205.0	40.8
30	29.4	5.9	90	88.3	17.6	150	147.1	29.3	210	206.0	41.0
31	30.4	6.0	91	89.3	17.8	151	148.1	29.5	211	206.9	41.2
32	31.4	6.2	92	90.2	17.9	152	149.1	29.7	212	207.9	41.4
33	32.4	6.4	93	91.2	18.1	153	150.1	29.8	213	208.9	41.6
34	33.3	6.6	94	92.2	18.3	154	151.0	30.0	214	209.9	41.7
35	34.3	6.8	95	93.2	18.5	155	152.0	30.2	215	210.9	41.9
36	35.3	7.0	96	94.2	18.7	156	153.0	30.4	216	211.8	42.1
37	36.3	7.2	97	95.1	18.9	157	154.0	30.6	217	212.8	42.3
38	37.3	7.4	98	96.1	19.1	158	155.0	30.8	218	213.8	42.5
39	38.3	7.6	99	97.1	19.	159	155.9	31.0	219	214.8	42.7
40	39.2	7.8	100	98.1	19.5	160	156.9	31.2	220	215.8	42.9
41	40.2	8.0	101	99.1	19.7	161	157.9	31.4	221	216.8	43.1
42	41.2	8.2	102	100.0	19.9	162	158.9	31.6	222	217.7	43.3
43	42.2	8.4	103	101.0	20.1	163	159.9	31.8	223	218.7	43.5
44	43.2	8.6	104	102.0	20.3	164	160.8	32.0	224	219.7	43.7
45	44.1	8.8	105	103.0	20.5	165	161.8	32.2	225	220.7	43.9
46	45.1	9.0	106	104.0	20.7	166	162.8	32.4	226	221.7	44.1
47	46.1	9.2	107	104.9	20.9	67	163.8	32.6	227	222.6	44.3
48	47.1	9.4	108	105.9	21	168	164.8	32.8	228	223.6	44.5
49	48.1	9.6	109	106.9	21.3	169	165.8	33.0	229	224.6	44.7
50	49.0	9.8	110	107.9	21.5	170	166.7	33.2	230	225.6	44.9
51	50.0	9.9	111	108.9	21.7	171	167.7	33.4	231	226.6	45.1
52	51.0	10.1	112	109.8	21.9	172	168.7	33.6	232	227.5	45.3
53	52.0	10.3	113	110.8	22.	173	169.7	33.8	233	228.5	45.5
54	53.0	10.5	114	111.8	22.2	74	170.7	33.9	234	229.5	45.7
55	53.9	10.7	115	112.8	22.4	175	171.6	34.1	235	230.5	45.8
56	54.9	10.9	116	113.8	22.6	176	172.6	34.3	236	231.5	4 .0
57	55.9	11.1	117	114.8	22.8	77	173.6	34.5	237	232.4	46.2
58	56.9	11.3	118	115.7	23.0	78	174.6	34.7	238	233.4	46.4
59	57.9	11.5	119	116.7	23.2	179	175.6	34.9	239	234.4	46.6
60	58.8	11.7	120	117.7	23.4	8	176.5	35.1	240	235.4	46.8
Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat
For 7 Points.											

TABLE I.—*Continued.*

Traverse Table to Points and Quarters of the Compass.

For 1¼ Point.												For 1½ Point.											
Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	1.0	0.2	61	59.2	14.8	121	117.4	29.4	181	175.6	44.0	1	1.0	0.3	61	58.4	17.7	121	115.8	35.1	181	173.2	52.5
2	1.9	0.5	62	60.1	15.1	122	118.3	29.6	182	176.5	44.2	2	1.9	0.6	62	59.3	18.0	122	116.7	35.4	182	174.2	52.8
3	2.9	0.7	63	61.1	15.3	123	119.3	29.9	183	177.5	44.5	3	2.9	0.9	63	60.3	18.3	123	117.7	35.7	183	175.1	53.1
4	3.9	1.0	64	62.1	15.6	124	120.3	30.1	184	178.5	44.7	4	3.8	1.2	64	61.2	18.6	124	118.7	36.0	184	176.1	53.4
5	4.9	1.2	65	63.1	15.8	125	121.3	30.4	185	179.5	45.0	5	4.8	1.5	65	62.2	18.9	125	119.6	36.3	185	177.0	53.7
6	5.8	1.5	66	64.0	16.0	126	122.2	30.6	186	180.4	45.2	6	5.8	1.7	66	63.2	19.2	126	120.6	36.6	186	178.0	54.0
7	6.8	1.7	67	65.0	16.3	127	123.2	30.9	187	181.4	45.4	7	6.7	2.0	67	64.1	19.4	127	121.5	36.9	187	178.9	54.3
8	7.8	1.9	68	66.0	16.5	128	124.2	31.1	188	182.4	45.7	8	7.7	2.3	68	65.1	19.7	128	122.5	37.2	188	179.9	54.6
9	8.7	2.2	69	66.9	16.8	129	125.1	31.3	189	183.3	45.9	9	8.6	2.6	69	66.0	20.0	129	123.4	37.4	189	180.9	54.9
10	9.7	2.4	70	67.9	17.0	130	126.1	31.6	190	184.3	46.2	10	9.6	2.9	70	67.0	20.3	130	124.4	37.7	190	181.8	55.2
11	10.7	2.7	71	68.9	17.3	131	127.1	31.8	191	185.3	46.4	11	10.5	3.2	71	67.9	20.6	131	125.4	38.0	191	182.8	55.4
12	11.6	2.9	72	69.8	17.5	132	128.0	32.1	192	186.2	46.7	12	11.5	3.5	72	68.9	20.9	132	126.3	38.3	192	183.7	55.7
13	12.6	3.2	73	70.8	17.7	133	129.0	32.3	193	187.2	46.9	13	12.4	3.8	73	69.9	21.2	133	127.3	38.6	193	184.7	56.0
14	13.6	3.4	74	71.8	18.0	134	130.0	32.6	194	188.2	47.1	14	13.4	4.1	74	70.8	21.5	134	128.2	38.9	194	185.6	56.3
15	14.6	3.6	75	72.8	18.2	135	131.0	32.8	195	189.2	47.4	15	14.4	4.4	75	71.8	21.8	135	129.2	39.2	195	186.6	56.6
16	15.5	3.9	76	73.7	18.5	136	131.9	33.0	196	190.1	47.6	16	15.3	4.6	76	72.7	22.1	136	130.1	39.5	196	187.6	56.9
17	16.5	4.1	77	74.7	18.7	137	132.9	33.3	197	191.1	47.9	17	16.3	4.9	77	73.7	22.4	137	131.1	39.8	197	188.5	57.2
18	17.5	4.4	78	75.7	19.0	138	133.9	33.5	198	192.1	48.1	18	17.2	5.2	78	74.6	22.6	138	132.1	40.1	198	189.5	57.5
19	18.4	4.6	79	76.6	19.2	139	134.8	33.8	199	193.0	48.4	19	18.2	5.5	79	75.6	22.9	139	133.0	40.3	199	190.4	57.8
20	19.4	4.9	80	77.6	19.4	140	135.8	34.0	200	194.0	48.6	20	19.1	5.8	80	76.6	23.2	140	134.0	40.6	200	191.4	58.1
21	20.4	5.1	81	78.6	19.7	141	136.8	34.3	201	195.0	48.8	21	20.1	6.1	81	77.5	23.5	141	134.9	40.9	201	192.3	58.3
22	21.3	5.3	82	79.5	19.9	142	137.7	34.5	202	195.9	49.1	22	21.1	6.4	82	78.5	23.8	142	135.9	41.2	202	193.3	58.6
23	22.3	5.6	83	80.5	20.2	143	138.7	34.7	203	196.9	49.3	23	22.0	6.7	83	79.4	24.1	143	136.8	41.5	203	194.3	58.9
24	23.3	5.8	84	81.5	20.4	144	139.7	35.0	204	197.9	49.6	24	23.0	7.0	84	80.4	24.4	144	137.8	41.8	204	195.2	59.2
25	24.3	6.1	85	82.5	20.7	145	140.7	35.2	205	198.9	49.8	25	23.9	7.3	85	81.3	24.7	145	138.8	42.1	205	196.2	59.5
26	25.2	6.3	86	83.4	20.9	146	141.6	35.5	206	199.8	50.1	26	24.9	7.5	86	82.3	25.0	146	139.7	42.4	206	197.1	59.8
27	26.2	6.6	87	84.4	21.1	147	142.6	35.7	207	200.8	50.3	27	25.8	7.8	87	83.3	25.3	147	140.7	42.7	207	198.1	60.1
28	27.2	6.8	88	85.4	21.4	148	143.6	36.0	208	201.8	50.5	28	26.8	8.1	88	84.2	25.5	148	141.6	43.0	208	199.0	60.4
29	28.1	7.0	89	86.3	21.6	149	144.5	36.2	209	202.7	50.8	29	27.8	8.4	89	85.2	25.8	149	142.6	43.3	209	200.0	60.7
30	29.1	7.3	90	87.3	21.9	150	145.5	36.4	210	203.7	51.0	30	28.7	8.7	90	86.1	26.1	150	143.5	43.5	210	201.0	61.0
31	30.1	7.5	91	88.3	22.1	151	146.5	36.7	211	204.7	51.3	31	29.7	9.0	91	87.1	26.4	151	144.5	43.8	211	201.9	61.3
32	31.0	7.8	92	89.2	22.4	152	147.4	36.9	212	205.6	51.5	32	30.6	9.3	92	88.0	26.7	152	145.5	44.1	212	202.9	61.5
33	32.0	8.0	93	90.2	22.6	153	148.4	37.2	213	206.6	51.8	33	31.6	9.6	93	89.0	27.0	153	146.4	44.4	213	203.8	61.8
34	33.0	8.3	94	91.2	22.8	154	149.4	37.4	214	207.6	52.0	34	32.5	9.9	94	90.0	27.3	154	147.4	44.7	214	204.8	62.1
35	34.0	8.5	95	92.2	23.1	155	150.4	37.7	215	208.6	52.2	35	33.5	10.2	95	90.9	27.6	155	148.3	45.0	215	205.7	62.4
36	34.9	8.7	96	93.1	23.3	156	151.3	37.9	216	209.5	52.5	36	34.4	10.5	96	91.9	27.9	156	149.3	45.3	216	206.7	62.7
37	35.9	9.0	97	94.1	23.6	157	152.3	38.1	217	210.5	52.7	37	35.4	10.7	97	92.8	28.2	157	150.2	45.6	217	207.7	63.0
38	36.9	9.2	98	95.1	23.8	158	153.3	38.4	218	211.5	53.0	38	36.4	11.0	98	93.8	28.4	158	151.2	45.9	218	208.6	63.3
39	37.8	9.5	99	96.0	24.1	159	154.2	38.6	219	212.4	53.2	39	37.3	11.3	99	94.7	28.7	159	152.2	46.2	219	209.6	63.6
40	38.8	9.7	100	97.0	24.3	160	155.2	38.9	220	213.4	53.5	40	38.3	11.6	100	95.7	29.0	160	153.1	46.4	220	210.5	63.9
41	39.8	10.0	101	98.0	24.5	161	156.2	39.1	221	214.4	53.7	41	39.2	11.9	101	96.7	29.3	161	154.1	46.7	221	211.5	64.2
42	40.7	10.2	102	98.9	24.8	162	157.1	39.4	222	215.3	53.9	42	40.2	12.2	102	97.6	29.6	162	155.0	47.0	222	212.4	64.4
43	41.7	10.4	103	99.9	25.0	163	158.1	39.6	223	216.3	54.2	43	41.1	12.5	103	98.6	29.9	163	156.0	47.3	223	213.4	64.7
44	42.7	10.7	104	100.9	25.3	164	159.1	39.8	224	217.3	54.4	44	42.1	12.8	104	99.5	30.2	164	156.9	47.6	224	214.4	65.0
45	43.7	10.9	105	101.9	25.5	165	160.1	40.1	225	218.3	54.7	45	43.1	13.1	105	100.5	30.5	165	157.9	47.9	225	215.3	65.3
46	44.6	11.2	106	102.8	25.8	166	161.0	40.3	226	219.2	54.9	46	44.0	13.4	106	101.4	30.8	166	158.9	48.2	226	216.3	65.6
47	45.6	11.4	107	103.8	26.0	167	162.0	40.6	227	220.2	55.2	47	45.0	13.6	107	102.4	31.1	167	159.8	48.5	227	217.2	65.9
48	46.6	11.7	108	104.8	26.2	168	163.0	40.8	228	221.2	55.4	48	45.9	13.9	108	103.3	31.4	168	160.8	48.8	228	218.2	66.2
49	47.5	11.9	109	105.7	26.5	169	163.9	41.1	229	222.1	55.6	49	46.9	14.2	109	104.3	31.6	169	161.7	49.1	229	219.1	66.5
50	48.5	12.1	110	106.7	26.7	170	164.9	41.3	230	223.1	55.9	50	47.8	14.5	110	105.3	31.9	170	162.7	49.3	230	220.1	66.8
51	49.5	12.4	111	107.7	27.0	171	165.9	41.5	231	224.1	56.1	51	48.8	14.8	111	106.2	32.2	171	163.6	49.6	231	221.1	67.1
52	50.4	12.6	112	108.6	27.2	172	166.8	41.8	232	225.0	56.4	52	49.8	15.1	112	107.2	32.5	172	164.6	49.9	232	222.0	67.3
53	51.4	12.9	113	109.6	27.5	173	167.8	42.0	233	226.0	56.6	53	50.7	15.4	113	108.1	32.8	173	165.6	50.2	233	223.0	67.6
54	52.4	13.1	114	110.6	27.7	174	168.8	42.3	234	227.0	56.8	54	51.7	15.7	114	109.1	33.1	174	166.5	50.5	234	223.9	67.9
55	53.4	13.4	115	111.6	27.9	175	169.8	42.5	235	228.0	57.1	55	52.6	16.0	115	110.0	33.4	175	167.5	50.8	235	224.9	68.2
56	54.3	13.6	116	112.5	28.2	176	170.7	42.8	236	228.9	57.3	56	53.6	16.3	116	111.0	33.7	176	168.4	51.1	236	225.8	68.5
57	55.3	13.8	117	113.5	28.4	177	171.7	43.0	237	229.9	57.6	57	54.5	16.5	117	112.0	34.0	177	169.4	51.4	237	226.8	68.8
58	56.3	14.1	118	114.5	28.7	178	172.7	43.3	238	230.9	57.8	58	55.5	16.8	118	112.9	34.3	178	170.3	51.7	238	227.8	69.1
59	57.2	14.3	119	115.4	28.9	179	173.6	43.5	239	231.8	58.1	59	56.5	17.1	119	113.9	34.5	179	171.3	52.0	239	228.7	69.4
60	58.2	14.6	120	116.4	29.2	180	174.6	43.7	240	232.8	58.3	60	57.4	17.4	120	114.8	34.8	180	172.2	52.3	240	229.7	69.7
Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.
For 6¾ Points.												For 6½ Points.											

TABLE I.—*Continued.*

Traverse Table to Points and Quarters of the Compass.

For 1¾ Points.											
Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	0.9	0.3	61	57.4	20.6	121	113.9	40.8	181	170.4	61.0
2	1.9	0.7	62	58.4	20.9	122	114.9	41.1	182	171.4	61.3
3	2.8	1.0	63	59.3	21.2	123	115.8	41.4	183	172.3	61.7
4	3.8	1.3	64	60.3	21.6	124	116.8	41.8	184	173.2	62.0
5	4.7	1.7	65	61.2	21.9	125	117.7	42.1	185	174.2	62.3
6	5.6	2.0	66	62.1	22.2	126	118.6	42.4	186	175.1	62.7
7	6.6	2.4	67	63.1	22.6	127	119.6	42.8	187	176.1	63.0
8	7.5	2.7	68	64.0	22.9	128	120.5	43.1	188	177.0	63.3
9	8.5	3.0	69	65.0	23.2	129	121.5	43.5	189	178.0	63.7
10	9.4	3.4	70	65.9	23.6	130	122.4	43.8	190	178.9	64.0
11	10.4	3.7	71	66.8	23.9	131	123.3	44.1	191	179.8	64.3
12	11.3	4.0	72	67.8	24.3	132	124.3	44.5	192	180.8	64.7
13	12.2	4.4	73	68.7	24.6	133	125.2	44.8	193	181.7	65.0
14	13.2	4.7	74	69.7	24.9	134	126.2	45.1	194	182.7	65.4
15	14.1	5.1	75	70.6	25.3	135	127.1	45.5	195	183.0	65.7
16	15.1	5.4	76	71.6	25.6	136	128.0	45.8	196	184.5	66.0
17	16.0	5.7	77	72.5	25.9	137	129.0	46.2	197	185.5	66.4
18	16.9	6.1	78	73.4	26.3	138	129.9	46.5	198	186.4	66.7
19	17.9	6.4	79	74.4	26.6	139	130.9	46.8	199	187.4	67.0
20	18.8	6.7	80	75.3	27.0	140	131.8	47.2	200	188.3	67.4
21	19.8	7.1	81	76.3	27.3	141	132.8	47.5	201	189.3	67.7
22	20.7	7.4	82	77.2	27.6	142	133.7	47.8	202	190.2	68.1
23	21.7	7.7	83	78.1	28.0	143	134.6	48.2	203	191.1	68.4
24	22.6	8.1	84	79.1	28.3	144	135.6	48.5	204	192.1	68.7
25	23.5	8.4	85	80.0	28.6	145	136.5	48.8	205	193.0	69.1
26	24.5	8.8	86	81.0	29.0	146	137.5	49.2	206	194.0	69.4
27	25.4	9.1	87	81.9	29.3	147	138.4	49.5	207	195.9	69.7
28	26.4	9.4	88	82.9	29.6	148	139.3	49.9	208	196.8	70.1
29	27.3	9.8	89	83.8	30.0	149	140.3	50.2	209	196.8	70.4
30	28.2	10.1	90	84.7	30.3	150	141.2	50.5	210	197.7	70.7
31	29.2	10.4	91	85.7	30.7	151	142.2	50.9	211	198.7	71.1
32	30.1	10.8	92	86.6	31.0	152	143.1	51.2	212	199.6	71.4
33	31.1	11.1	93	87.6	31.3	153	144.1	51.5	213	200.5	71.8
34	32.0	11.5	94	88.5	31.7	154	145.0	51.9	214	201.5	72.1
35	33.0	11.8	95	89.4	32.0	155	145.9	52.2	215	202.4	72.4
36	33.9	12.1	96	90.4	32.3	156	146.9	52.6	216	203.4	72.8
37	34.8	12.5	97	91.3	32.7	157	147.8	52.9	217	204.3	73.1
38	35.8	12.8	98	92.3	33.0	158	148.8	53.2	218	205.3	73.4
39	36.7	13.1	99	93.2	33.4	159	149.7	53.6	219	206.2	73.8
40	37.7	13.5	100	94.2	33.7	160	150.6	53.9	220	207.1	74.1
41	38.6	13.8	101	95.1	34.0	161	151.6	54.2	221	208.1	74.5
42	39.5	14.1	102	96.0	34.4	162	152.5	54.6	222	209.0	74.8
43	40.5	14.5	103	97.0	34.7	163	153.5	54.9	223	210.0	75.1
44	41.4	14.8	104	97.9	35.0	164	154.4	55.2	224	210.9	75.5
45	42.4	15.2	105	98.9	35.4	165	155.4	55.6	225	211.8	75.8
46	43.3	15.5	106	99.8	35.7	166	156.3	55.9	226	212.8	76.1
47	44.3	15.8	107	100.7	36.0	167	157.2	56.3	227	213.7	76.5
48	45.2	16.2	108	101.7	36.4	168	158.2	56.6	228	214.7	76.8
49	46.1	16.5	109	102.6	36.7	169	159.1	56.9	229	215.6	77.1
50	47.1	16.8	110	103.6	37.1	170	160.1	57.3	230	216.6	77.5
51	48.0	17.2	111	104.5	37.4	171	161.0	57.6	231	217.5	77.8
52	49.0	17.5	112	105.5	37.7	172	161.9	57.9	232	218.4	78.2
53	49.9	17.9	113	106.4	38.1	173	162.9	58.3	233	219.4	78.5
54	50.8	18.2	114	107.3	38.4	174	163.8	58.6	234	220.3	78.8
55	51.8	18.5	115	108.3	38.7	175	164.8	59.0	235	221.3	79.2
56	52.7	18.9	116	109.2	39.1	176	165.7	59.3	236	222.2	79.5
57	53.7	19.2	117	110.2	39.4	177	166.7	59.6	237	223.1	79.8
58	54.6	19.5	118	111.1	39.8	178	167.6	60.0	238	224.1	80.2
59	55.6	19.9	119	112.0	40.1	179	168.5	60.3	239	225.0	80.5
60	56.5	20.2	120	113.0	40.4	180	169.5	60.6	240	226.0	80.9
Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat
For 6¼ Points.											

For 2 Points.											
Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	0.9	0.4	61	56.4	23.3	121	111.8	46.3	181	167.2	69.3
2	1.8	0.8	62	57.3	23.7	122	112.7	46.7	182	168.1	69.6
3	2.8	1.1	63	58.2	24.1	123	113.6	47.1	183	169.1	70.0
4	3.7	1.5	64	59.1	24.5	124	114.6	47.5	184	170.0	70.4
5	4.6	1.9	65	60.1	24.9	125	115.5	47.8	185	170.9	70.8
6	5.5	2.3	66	61.0	25.3	126	116.4	48.2	186	171.8	71.2
7	6.5	2.7	67	61.9	25.6	127	117.3	48.6	187	172.8	71.6
8	7.4	3.1	68	62.8	26.0	128	118.3	49.0	188	173.7	71.9
9	8.3	3.4	69	63.7	26.4	129	119.2	49.4	189	174.6	72.3
10	9.2	3.8	70	64.7	26.8	130	120.1	49.7	190	175.5	72.7
11	10.2	4.2	71	65.0	27.2	131	121.0	50.1	191	176.5	73.1
12	11.1	4.6	72	66.5	27.6	132	122.0	50.5	192	177.4	73.5
13	12.0	5.0	73	67.4	27.9	133	122.9	50.9	193	178.3	73.9
14	12.9	5.4	74	68.4	28.3	134	123.8	51.3	194	179.2	74.2
15	13.9	5.7	75	69.3	28.7	135	124.7	51.7	195	180.2	74.6
16	14.8	6.1	76	70.2	29.1	136	125.6	52.0	196	181.1	75.0
17	15.7	6.5	77	71.1	29.5	137	126.6	52.4	197	182.0	75.4
18	16.6	6.9	78	72.1	29.8	138	127.5	52.8	198	182.9	75.8
19	17.6	7.3	79	73.0	30.2	139	128.4	53.2	199	183.9	76.2
20	18.5	7.7	80	73.9	30.6	140	129.3	53.6	200	184.8	76.5
21	19.4	8.0	81	74.8	31.0	141	130.3	54.0	201	185.7	76.9
22	20.3	8.4	82	75.8	31.4	142	131.2	54.3	202	186.6	77.3
23	21.2	8.8	83	76.7	31.8	143	132.1	54.7	203	187.5	77.7
24	22.2	9.2	84	77.6	32.1	144	133.0	55.1	204	188.5	78.1
25	23.1	9.6	85	78.5	32.5	145	134.0	55.5	205	189.4	78.5
26	24.0	9.9	86	79.5	32.9	146	134.9	55.9	206	190.3	78.8
27	24.9	10.3	87	80.4	33.3	147	135.8	56.3	207	191.2	79.2
28	25.9	10.7	88	81.3	33.7	148	136.7	56.6	208	192.2	79.6
29	26.8	11.1	89	82.2	34.1	149	137.7	57.0	209	193.1	80.0
30	27.7	11.5	90	83.1	34.4	150	138.6	57.4	210	194.0	80.4
31	28.6	11.9	91	84.1	34.8	151	139.5	57.8	211	194.9	80.7
32	29.6	12.2	92	85.0	35.2	152	140.4	58.2	212	195.9	31.1
33	30.5	12.6	93	85.9	35.6	153	141.4	58.6	213	196.8	81.5
34	31.4	13.0	94	86.8	36.0	154	142.3	58.9	214	197.7	81.9
35	32.3	13.4	95	87.8	36.4	155	143.2	59.3	215	198.6	82.3
36	33.3	13.8	96	88.7	36.7	156	144.1	59.7	216	199.6	82.7
37	34.2	14.2	97	89.6	37.1	157	145.0	60.1	217	200.5	83.0
38	35.1	14.5	98	90.5	37.5	158	146.0	60.5	218	201.4	83.4
39	36.0	14.9	99	91.5	37.9	159	146.9	60.8	219	202.3	83.8
40	37.0	15.3	100	92.4	38.3	160	147.8	61.2	220	203.3	84.2
41	37.9	15.7	101	93.3	38.7	161	148.7	61.6	221	204.2	84.6
42	38.8	16.1	102	94.2	39.0	162	149.7	62.0	222	205.1	85.0
43	39.7	16.5	103	95.2	39.4	163	150.6	62.4	223	206.0	85.3
44	40.7	16.8	104	96.1	39.8	164	151.5	62.8	224	206.9	85.7
45	41.6	17.2	105	97.0	40.2	165	152.4	63.1	225	207.9	86.1
46	42.5	17.6	106	97.9	40.6	166	153.4	63.5	226	208.8	86.5
47	43.4	18.0	107	98.9	40.9	167	154.3	63.9	227	209.7	86.9
48	44.3	18.4	108	99.8	41.3	168	155.2	64.3	228	210.6	87.3
49	45.3	18.8	109	100.7	41.7	169	156.1	64.7	229	211.6	87.6
50	46.2	19.1	110	101.6	42.1	170	157.1	65.1	230	212.5	88.0
51	47.1	19.5	111	102.6	42.5	171	158.0	65.4	231	213.4	88.4
52	48.0	19.9	112	103.5	42.9	172	158.9	65.8	232	214.3	88.8
53	49.0	20.3	113	104.4	43.2	173	159.8	66.2	233	215.3	89.2
54	49.9	20.7	114	105.3	43.6	174	160.8	66.6	234	216.2	89.5
55	50.8	21.0	115	106.2	44.0	175	161.7	67.0	235	217.1	59.9
56	51.7	21.4	116	107.2	44.4	176	162.6	67.4	236	218.0	90.3
57	52.7	21.8	117	108.1	44.8	177	163.5	67.7	237	219.0	90.7
58	53.6	22.2	118	109.0	45.2	178	164.5	68.1	238	219.9	91.1
59	54.5	22.6	119	109.9	45.5	179	165.4	68.5	239	220.8	91.5
60	55.4	23.0	120	110.9	45.9	180	166.3	68.9	240	221.7	91.8
Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat
For 6 Points.											

TABLE I.—*Continued.*

Traverse Table to Points and Quarters of the Compass.

For 2¼ Points.											
Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	0.9	0.4	61	55.1	26.1	121	109.4	51.7	181	163.6	77.4
2	1.8	0.9	62	56.0	26.5	122	110.3	52.2	182	164.5	77.8
3	2.7	1.3	63	57.0	26.9	123	111.2	52.6	183	165.4	78.2
4	3.6	1.7	64	57.9	27.4	124	112.1	53.0	184	166.3	78.7
5	4.5	2.1	65	58.8	27.8	125	113.0	53.4	185	167.2	79.1
6	5.4	2.6	66	59.7	28.2	126	113.9	53.9	186	168.1	79.5
7	6.3	3.0	67	60.6	28.6	127	114.8	54.3	187	169.0	80.0
8	7.2	3.4	68	61.5	29.1	128	115.7	54.7	188	169.9	80.4
9	8.1	3.8	69	62.4	29.5	129	116.6	55.2	189	170.9	80.8
10	9.0	4.3	70	63.3	29.9	130	117.5	55.6	190	171.8	81.2
11	9.9	4.7	71	64.2	30.4	131	118.4	56.0	191	172.7	81.7
12	10.8	5.1	72	65.1	30.8	132	119.3	56.4	192	173.6	82.1
13	11.8	5.6	73	66.0	31.2	133	120.2	56.9	193	174.5	82.5
14	12.7	6.0	74	66.9	31.6	134	121.1	57.3	194	175.4	82.9
15	13.6	6.4	75	67.8	32.1	135	122.0	57.7	195	176.3	83.4
16	14.5	6.8	76	68.7	32.5	136	122.9	58.1	196	177.2	83.8
17	15.4	7.3	77	69.6	32.9	137	123.8	58.6	197	178.1	84.2
18	16.3	7.7	78	70.5	33.3	138	124.8	59.0	198	179.0	84.7
19	17.2	8.1	79	71.4	33.8	139	125.7	59.4	199	179.9	85.1
20	18.1	8.6	80	72.3	34.2	140	126.6	59.9	200	180.8	85.5
21	19.0	9.0	81	73.2	34.6	141	127.5	60.8	201	181.7	85.9
22	19.9	9.4	82	74.1	35.1	142	128.4	60.7	202	182.6	86.4
23	20.8	9.8	83	75.0	35.5	143	129.3	61.1	203	183.5	86.8
24	21.7	10.3	84	75.9	35.9	144	130.2	61.6	204	184.4	87.0
25	22.6	10.7	85	76.8	36.3	145	131.1	62.0	205	185.3	87.6
26	23.5	11.1	86	77.7	36.8	146	132.0	62.4	206	186.2	88.1
27	24.4	11.5	87	78.6	37.2	147	132.9	62.9	207	187.1	88.5
28	25.3	12.0	88	79.6	37.6	148	133.8	63.3	208	188.0	88.9
29	26.2	12.4	89	80.5	38.1	149	134.7	63.7	209	188.9	89.4
30	27.1	12.8	90	81.4	38.5	150	135.6	64.1	210	189.8	89.8
31	28.0	13.3	91	82.3	38.9	151	136.5	64.6	211	190.7	90.2
32	28.9	13.7	92	83.2	39.3	152	137.4	65.0	212	191.6	90.6
33	29.8	14.1	93	84.1	39.8	153	138.3	65.4	213	192.5	91.1
34	30.7	14.5	94	85.0	40.2	154	139.2	65.8	214	193.5	91.5
35	31.6	15.0	95	85.9	40.6	155	140.1	66.3	215	194.4	91.9
36	32.5	15.4	96	86.8	41.0	156	141.0	66.7	216	195.3	92.4
37	33.4	15.8	97	87.7	41.5	157	141.9	67.9	217	196.2	92.8
38	34.4	16.2	98	88.6	41.9	158	142.8	67.6	218	197.1	93.2
39	35.3	16.7	99	89.5	42.3	159	143.7	68.0	219	198.0	93.6
40	36.2	17.1	100	90.4	42.8	160	144.6	68.4	220	198.9	94.1
41	37.1	17.5	101	91.3	43.2	161	145.5	68.8	221	199.8	94.5
42	38.0	18.0	102	92.2	43.6	162	146.4	69.3	222	200.7	94.9
43	38.9	18.4	103	93.1	44.0	163	147.4	69.7	223	201.6	95.3
44	39.8	18.8	104	94.0	44.5	164	148.3	70.1	224	202.5	95.8
45	40.7	19.2	105	94.9	44.9	165	149.2	70.5	225	203.4	96.2
46	41.6	19.7	106	95.8	45.3	166	150.1	71.0	226	204.3	96.6
47	42.5	20.1	107	96.7	45.7	167	151.0	71.4	227	205.2	97.1
48	43.4	20.5	108	97.6	46.2	168	151.9	71.8	228	206.1	97.5
49	44.3	21.0	109	98.5	46.6	169	152.8	72.3	229	207.0	97.9
50	45.2	21.4	110	99.4	47.0	170	153.7	72.7	230	207.9	98.3
51	46.1	21.8	111	100.3	47.5	171	154.6	73.1	231	208.8	98.8
52	47.0	22.2	112	101.2	47.9	172	155.5	73.5	232	209.7	99.2
53	47.9	22.7	113	102.2	48.3	173	156.4	74.0	233	210.6	99.6
54	48.8	23.1	114	103.1	48.7	174	157.3	74.4	234	211.5	100.0
55	49.7	23.5	115	104.0	49.2	175	158.2	74.8	235	212.4	100.5
56	50.6	23.9	116	104.9	49.6	176	159.1	75.2	236	213.3	100.9
57	51.5	24.4	117	105.8	50.0	177	160.0	75.7	237	214.2	101.3
58	52.4	24.8	118	106.7	50.5	178	160.9	76.1	238	215.1	101.8
59	53.3	25.2	119	107.6	50.9	179	161.8	76.5	239	216.1	102.2
60	54.2	25.7	120	108.5	51.3	180	162.7	77.0	240	217.0	102.6
Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D. Lat.
For 5¾ Points.											

For 2½ Points.											
Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	0.9	0.5	61	53.8	28.8	121	106.7	57.0	181	159.6	85.3
2	1.8	0.9	62	54.7	29.2	122	107.6	57.5	182	160.5	85.8
3	2.6	1.4	63	55.6	29.7	123	108.5	58.0	183	161.4	86.3
4	3.5	1.9	64	56.4	30.2	124	109.4	58.5	184	162.3	86.7
5	4.4	2.4	65	57.3	30.6	125	110.2	58.9	185	163.2	87.2
6	5.3	2.8	66	58.2	31.1	126	111.1	59.4	186	164.0	87.7
7	6.2	3.4	67	59.1	31.6	127	112.0	59.9	187	164.9	88.2
8	7.1	3.8	68	60.0	32.1	128	112.9	60.3	188	165.8	88.6
9	7.9	4.2	69	60.9	32.5	129	113.8	60.8	189	166.7	89.1
10	8.8	4.7	70	61.7	33.0	130	114.6	61.3	190	167.0	89.6
11	9.7	5.2	71	62.6	33.5	131	115.5	61.8	191	168.4	90.0
12	10.6	5.7	72	63.5	33.9	132	116.4	62.2	192	169.3	90.5
13	11.5	6.1	73	64.4	34.4	133	117.3	62.7	193	170.2	91.0
14	12.3	6.6	74	65.3	34.9	134	118.2	63.2	194	171.1	91.5
15	13.2	7.1	75	66.1	35.4	135	119.1	63.6	195	172.0	91.9
16	14.1	7.5	76	67.0	35.8	136	119.9	64.1	196	172.9	92.4
17	15.0	8.0	77	67.9	36.3	137	120.8	64.6	197	173.7	92.9
18	15.9	8.5	78	68.8	36.8	138	121.7	65.1	198	174.6	93.3
19	16.8	9.0	79	69.7	37.2	139	122.6	65.5	199	175.5	93.8
20	17.6	9.4	80	70.6	37.7	140	123.5	66.0	200	176.4	94.3
21	18.5	9.9	81	71.4	38.2	141	124.4	66.5	201	177.3	94.8
22	19.4	10.4	82	72.3	38.7	142	125.2	66.9	202	178.1	95.2
23	20.3	10.8	83	73.2	39.1	143	126.1	67.4	203	179.0	95.7
24	21.2	11.3	84	74.1	39.6	144	127.0	67.9	204	179.9	96.2
25	22.0	11.8	85	75.0	40.1	145	127.9	68.4	205	180.8	96.6
26	22.9	12.3	86	75.8	40.5	146	128.8	68.8	206	181.7	97.1
27	23.8	12.7	87	76.7	41.0	147	129.6	69.3	207	182.6	97.6
28	24.7	13.2	88	77.6	41.5	148	130.5	69.8	208	183.4	98.1
29	25.6	13.7	89	78.5	42.0	149	131.4	70.2	209	184.3	98.5
30	26.5	14.1	90	79.4	42.4	150	132.3	70.7	210	185.2	99.0
31	27.3	14.6	91	80.3	42.9	151	133.2	71.2	211	186.1	99.5
32	28.2	15.1	92	81.1	43.4	152	134.1	71.7	212	187.0	99.9
33	29.1	15.1	93	82.0	43.8	153	134.9	72.1	213	187.8	100.4
34	30.0	16.0	94	82.9	44.3	154	135.8	72.6	214	188.7	100.9
35	30.9	16.5	95	83.8	44.8	155	136.7	73.1	215	189.6	101.4
36	31.7	17.0	96	84.7	45.3	156	137.6	73.5	216	190.5	101.8
37	32.6	17.4	97	85.5	45.7	157	138.5	74.0	217	191.4	102.3
38	33.5	17.9	98	86.4	46.2	158	139.3	74.5	218	192.3	102.8
39	34.4	18.4	99	87.3	46.7	159	140.2	75.0	219	193.1	103.2
40	35.3	18.9	100	88.2	47.1	160	141.1	75.4	220	194.0	103.7
41	36.2	19.3	101	89.1	47.6	161	142.0	75.9	221	194.9	104.2
42	37.0	19.8	102	90.0	48.1	162	142.9	76.4	222	195.8	104.7
43	37.9	20.3	103	90.8	48.6	163	143.8	76.8	223	196.7	105.1
44	38.8	20.7	104	91.7	49.0	164	144.6	77.3	224	197.6	105.6
45	39.7	21.2	105	92.6	49.5	165	145.5	77.8	225	198.4	106.1
46	40.6	21.7	106	93.5	50.0	166	146.4	78.3	226	199.3	106.5
47	41.5	22.2	107	94.4	50.4	167	147.3	78.7	227	200.2	107.0
48	42.3	22.6	108	95.2	50.9	168	148.2	79.2	228	201.1	107.5
49	43.2	23.1	109	96.1	51.4	169	149.0	79.7	229	202.0	107.9
50	44.1	23.6	110	97.0	51.9	170	149.9	80.1	230	202.8	108.4
51	45.0	24.0	111	97.9	52.3	171	150.8	80.6	231	203.7	108.9
52	45.9	24.5	112	98.8	52.8	172	151.7	81.1	232	204.6	109.4
53	46.7	25.0	113	99.7	53.8	173	152.6	81.6	233	205.5	109.8
54	47.6	25.5	114	100.5	53.7	174	153.5	82.0	234	206.4	110.3
55	48.5	25.9	115	101.4	54.2	175	154.3	82.5	235	207.3	110.8
56	49.4	26.4	116	102.3	54.7	176	155.2	83.0	236	208.1	111.2
57	50.3	26.9	117	103.2	55.2	177	156.1	83.4	237	209.0	111.7
58	51.2	27.3	118	104.1	55.6	178	157.0	83.9	238	209.9	112.2
59	52.0	27.8	119	104.9	56.1	179	157.9	84.4	239	210.8	112.7
60	52.9	28.3	120	105.8	56.6	180	158.7	84.9	240	211.7	113.1
Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D. Lat.
For 5½ Points.											

TABLE I.—*Continued.*

Traverse Table to Points and Quarters of the Compass.

For 2¾ Points.

Dist.	D. Lat	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	0.9	0.5	61	52.3	31.4	121	103.8	62.2	181	155.2	93.1
2	1.7	1.0	62	53.2	31.9	122	104.6	62.7	182	156.1	93.6
3	2.6	1.5	63	54.0	32.4	123	105.5	63.2	183	157.0	94.1
4	3.4	2.1	64	54.9	32.9	124	106.4	63.7	184	157.8	94.6
5	4.3	2.6	65	55.8	33.4	125	107.2	64.3	185	158.7	95.1
6	5.1	3.1	66	56.6	33.9	126	108.1	64.8	186	159.5	95.6
7	6.0	3.6	67	57.5	34.4	127	108.9	65.3	187	160.4	96.1
8	6.9	4.1	68	58.3	35.0	128	109.8	65.8	188	161.3	96.7
9	7.7	4.6	69	59.2	35.5	129	110.6	66.3	189	162.1	97.2
10	8.6	5.1	70	60.0	36.0	130	111.5	66.8	190	163.0	97.7
11	9.4	5.7	71	60.9	36.5	131	112.4	67.3	191	163.8	98.2
12	10.3	6.2	72	61.8	37.0	132	113.2	67.9	192	164.7	98.7
13	11.2	6.7	73	62.6	37.5	133	114.1	68.4	193	165.5	99.2
14	12.0	7.2	74	63.5	38.0	134	114.9	68.9	194	166.4	99.7
15	12.9	7.7	75	64.3	38.6	135	115.8	69.4	195	167.3	100.3
16	13.7	8.2	76	65.2	39.1	136	116.7	69.9	196	168.1	100.8
17	14.6	8.7	77	66.0	39.6	137	117.5	70.4	197	169.0	101.3
18	15.4	9.3	78	66.9	40.1	138	118.4	70.9	198	169.8	101.8
19	16.3	9.8	79	67.8	40.6	139	119.2	71.5	199	170.7	102.3
20	17.2	10.3	80	68.6	41.1	140	120.1	72.0	200	171.5	102.8
21	18.0	10.8	81	69.5	41.6	141	120.9	72.5	201	172.4	103.3
22	18.9	11.3	82	70.3	42.2	142	121.8	73.0	202	173.3	103.8
23	19.7	11.8	83	71.2	42.7	143	122.7	73.5	203	174.1	104.4
24	20.6	12.3	84	72.0	43.2	144	123.5	74.0	204	175.0	104.9
25	21.4	12.9	85	72.9	43.7	145	124.4	74.5	205	175.8	105.4
26	22.3	13.4	86	73.8	44.2	146	125.2	75.1	206	176.7	105.9
27	23.2	13.9	87	74.6	44.7	147	126.1	75.6	207	177.5	106.4
28	24.0	14.4	88	75.5	45.2	148	126.9	76.1	208	178.4	106.9
29	24.9	14.9	89	76.3	45.8	149	127.8	76.6	209	179.3	107.4
30	25.7	15.4	90	77.2	46.3	150	128.7	77.1	210	180.1	108.0
31	26.6	15.9	91	78.1	46.8	151	129.5	77.6	211	181.0	108.5
32	27.4	16.5	92	78.9	47.3	152	130.4	78.1	212	181.8	109.0
33	28.3	17.0	93	79.8	47.8	153	131.2	78.7	213	182.7	109.5
34	29.2	17.5	94	80.6	48.3	154	132.1	79.2	214	183.6	110.0
35	30.0	18.0	95	81.5	48.8	155	132.9	79.7	215	184.4	110.5
36	30.9	18.5	96	82.3	49.4	156	133.8	80.2	216	185.3	111.0
37	31.7	19.0	97	83.2	49.9	157	134.7	80.7	217	186.1	111.6
38	32.6	19.5	98	84.1	50.4	158	135.5	81.2	218	187.0	112.1
39	33.5	20.1	99	84.9	50.9	159	136.4	81.7	219	187.8	112.6
40	34.3	20.6	100	85.8	51.4	160	137.2	82.3	220	188.7	113.1
41	35.2	21.1	101	86.6	51.9	161	138.1	82.8	221	189.6	113.6
42	36.0	21.6	102	87.5	52.4	162	139.0	83.3	222	190.4	114.1
43	36.9	22.1	103	88.3	53.0	163	139.8	83.8	223	191.3	114.6
44	37.7	22.6	104	89.2	53.5	164	140.7	84.3	224	192.1	115.2
45	38.6	23.1	105	90.1	54.0	165	141.5	84.8	225	193.0	115.7
46	39.5	23.6	106	90.9	54.5	166	142.4	85.3	226	193.8	116.2
47	40.3	24.2	107	91.8	55.0	167	143.2	85.9	227	194.7	116.7
48	41.2	24.7	108	92.6	55.5	168	144.1	86.4	228	195.6	117.2
49	42.0	25.2	109	93.5	56.0	169	145.0	86.9	229	196.4	117.7
50	42.9	25.7	110	94.4	56.6	170	145.8	87.4	230	197.3	118.2
51	43.7	26.2	111	95.2	57.1	171	146.7	87.9	231	198.1	118.8
52	44.6	26.7	112	96.1	57.6	172	147.5	88.4	232	199.0	119.3
53	45.5	27.2	113	96.9	58.1	173	148.4	88.9	233	199.9	119.8
54	46.3	27.8	114	97.8	58.6	174	149.2	89.5	234	200.7	120.3
55	47.2	28.3	115	98.6	59.1	175	150.1	90.0	235	201.6	120.8
56	48.0	28.8	116	99.5	59.6	176	151.0	90.5	236	202.4	121.3
57	48.9	29.3	117	100.4	60.2	177	151.8	91.0	237	203.3	121.8
58	49.7	29.8	118	101.2	60.7	178	152.7	91.5	238	204.1	122.4
59	50.6	30.3	119	102.1	61.2	179	153.5	92.0	239	205.0	122.9
60	51.5	30.8	120	102.9	61.7	180	154.4	92.5	240	205.9	123.4
Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.

For 5¼ Points.

For 3 Points.

Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	0.8	0.6	61	50.7	33.9	121	100.0	67.0	181	150.5	100.5
2	1.7	1.1	62	51.6	34.4	122	101.4	67.8	182	151.3	101.1
3	2.5	1.7	63	52.4	35.0	123	102.3	68.3	183	152.2	101.7
4	3.3	2.2	64	53.2	35.6	124	103.1	68.9	184	153.0	102.2
5	4.2	2.8	65	54.0	36.1	125	103.9	69.4	185	153.8	102.8
6	5.0	3.3	66	55.9	36.7	126	104.8	70.0	186	154.7	103.5
7	5.8	3.9	67	55.7	37.2	127	105.6	70.5	187	155.5	103.9
8	6.7	4.4	68	56.5	37.8	128	106.4	71.1	188	156.3	104.1
9	7.5	5.0	69	57.4	38.3	129	107.3	71.7	189	157.1	105.0
10	8.3	5.6	70	58.3	38.9	130	108.1	72.2	190	158.0	105.5
11	9.1	6.1	71	59.0	39.4	131	108.9	72.8	191	158.8	106.1
12	10.0	6.7	72	59.9	40.0	132	109.8	73.3	192	159.6	106.7
13	10.8	7.2	73	60.7	40.6	133	110.6	73.9	193	160.5	107.2
14	11.6	7.8	74	61.5	41.1	134	111.4	74.4	194	161.3	107.8
15	12.5	8.3	75	62.4	41.7	135	112.2	75.0	195	162.1	108.3
16	13.3	8.9	76	63.2	42.2	136	113.1	75.5	196	163.0	108.9
17	14.1	9.4	77	64.0	42.8	137	113.9	76.1	197	163.8	109.4
18	15.0	10.0	78	64.9	43.3	138	114.7	76.7	198	164.6	110.0
19	15.8	10.6	79	65.7	43.9	139	115.6	77.2	199	165.5	110.5
20	16.6	11.1	80	66.5	44.4	140	116.4	77.8	200	166.3	111.1
21	17.5	11.7	81	67.3	45.0	141	117.2	78.3	201	167.1	111.7
22	18.3	12.2	82	68.2	45.6	142	118.1	78.9	202	168.6	112.2
23	19.1	12.8	83	69.0	46.1	143	118.9	79.4	203	168.8	112.8
24	20.0	13.3	84	69.8	46.7	144	119.7	80.0	204	169.6	113.3
25	20.8	13.9	85	70.7	47.2	145	120.6	80.5	205	170.5	113.9
26	21.6	14.4	86	71.5	47.8	146	121.4	81.1	206	171.3	114.4
27	22.4	15.0	87	72.3	48.3	147	122.2	81.7	207	172.1	115.0
28	23.3	15.6	88	73.2	48.9	148	123.1	82.2	208	172.9	115.5
29	24.1	16.1	89	74.0	49.4	149	123.9	82.8	209	173.8	116.1
30	24.9	16.7	90	74.8	50.0	150	124.7	83.3	210	174.6	116.7
31	25.8	17.2	91	75.7	50.6	151	125.6	83.9	211	175.4	117.2
32	26.6	17.8	92	76.5	51.1	152	126.4	84.4	212	176.3	117.8
33	27.4	18.3	93	77.3	51.7	153	127.2	85.0	213	177.1	118.3
34	28.3	18.9	94	78.2	52.2	154	128.0	85.5	214	177.9	118.9
35	29.1	19.4	95	79.0	52.8	155	128.9	86.1	215	178.8	119.4
36	29.9	20.0	96	79.8	53.3	156	129.7	86.7	216	179.6	120.0
37	30.8	20.6	97	80.7	53.9	157	130.5	87.2	217	180.4	120.5
38	31.6	21.1	98	81.5	54.4	158	131.4	87.8	218	181.3	121.1
39	32.4	21.7	99	82.2	55.0	159	132.2	88.3	219	182.1	121.7
40	33.3	22.2	100	83.1	55.6	160	133.0	88.9	220	182.9	122.2
41	34.1	22.8	101	84.0	56.1	161	133.9	89.4	221	183.8	122.8
42	34.9	23.3	102	84.8	56.7	162	134.7	90.0	222	184.6	123.3
43	35.8	23.9	103	85.6	57.2	163	135.5	90.5	223	185.4	123.9
44	36.6	24.4	104	86.5	57.8	164	136.4	91.1	224	186.2	124.4
45	37.4	25.0	105	87.3	58.3	165	137.2	91.7	225	187.1	125.0
46	38.2	25.6	106	88.1	58.9	166	138.0	92.2	226	187.9	125.5
47	39.1	26.1	107	89.0	59.4	167	138.9	92.8	227	188.7	126.1
48	39.9	26.7	108	89.8	60.0	168	139.7	93.3	228	189.6	126.7
49	40.7	27.2	109	90.6	60.6	169	140.5	93.9	229	190.4	127.2
50	41.6	27.8	110	91.5	61.1	170	141.3	94.4	230	191.2	127.8
51	42.4	28.3	111	92.3	61.7	171	142.2	95.0	231	192.1	128.3
52	43.2	28.9	112	93.1	62.2	172	143.0	95.5	232	192.9	128.9
53	44.1	29.4	113	94.0	62.8	173	143.8	96.1	233	193.7	129.4
54	44.9	30.0	114	94.8	63.3	174	144.7	96.7	234	194.6	130.0
55	45.7	30.6	115	95.6	63.9	175	145.5	97.2	235	195.4	130.5
56	46.6	31.1	116	96.5	64.4	176	146.3	97.8	236	196.2	131.1
57	47.4	31.7	117	97.3	65.0	177	147.2	98.3	237	197.1	131.7
58	48.2	32.2	118	98.1	65.5	178	148.0	98.9	238	197.9	132.2
59	49.1	32.8	119	98.9	66.1	179	148.8	99.4	239	198.7	132.8
60	49.9	33.3	120	99.8	66.7	180	149.7	100.0	240	199.6	133.8
Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.

For 5 Points.

TABLE I.—*Continued.*

Traverse Table to Points and Quarters of the Compass.

For 3¼ Points.

Dist.	D.Lat	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	0.8	0.6	61	49.0	36.3	121	97.2	72.1	181	145.4	107.8
2	1.0	1.2	62	49.8	36.9	122	98.0	72.7	182	146.2	108.4
3	2.4	1.8	63	50.6	37.5	123	98.8	73.3	183	147.0	109.0
4	3.2	2.4	64	51.4	38.1	124	99.6	73.9	184	147.8	109.6
5	4.0	3.0	65	52.2	38.7	125	100.4	74.5	185	148.6	110.2
6	4.8	3.6	66	53.0	39.3	126	101.2	75.1	186	149.4	110.8
7	5.6	4.2	67	53.8	39.9	127	102.0	75.7	187	150.2	111.4
8	6.4	4.8	68	54.6	40.5	128	102.8	76.2	188	151.0	112.0
9	7.2	5.4	69	55.4	41.1	129	103.6	76.8	189	151.8	112.6
10	8.0	6.0	70	56.2	41.7	130	104.4	77.4	190	152.6	113.2
11	8.8	6.6	71	57.0	42.3	131	105.2	78.0	191	153.4	113.8
12	9.6	7.1	72	57.8	42.9	132	106.0	78.6	192	154.2	114.4
13	10.4	7.7	73	58.6	43.5	133	106.8	79.2	193	155.0	115.0
14	11.2	8.3	74	59.4	44.1	134	107.6	79.8	194	155.8	115.6
15	12.0	8.9	75	60.2	44.7	135	108.4	80.4	195	156.6	116.2
16	12.9	9.5	76	61.0	45.3	136	109.2	81.0	196	157.4	116.8
17	13.7	10.1	77	61.8	45.9	137	110.0	81.6	197	158.2	117.4
18	14.5	10.7	78	62.7	46.5	138	110.8	82.2	198	159.0	117.9
19	15.3	11.3	79	63.5	47.1	139	111.6	82.8	199	159.8	118.5
20	16.1	11.9	80	64.3	47.7	140	112.4	83.4	200	160.6	119.1
21	16.9	12.5	81	65.1	48.3	141	113.3	84.0	201	161.4	119.7
22	17.7	13.1	82	65.9	48.8	142	114.1	84.6	202	162.2	120.3
23	18.5	13.7	83	66.7	49.4	143	114.9	85.2	203	163.1	120.9
24	19.3	14.3	84	67.5	50.0	144	115.7	85.8	204	163.9	121.5
25	20.1	14.9	85	68.3	50.6	145	116.5	86.4	205	164.7	122.1
26	20.9	15.5	86	69.1	51.2	146	117.3	87.0	206	155.5	122.7
27	21.7	16.1	87	69.9	51.8	147	118.1	87.6	207	166.3	123.3
28	22.5	16.7	88	70.7	52.4	148	118.9	88.2	208	167.1	123.9
29	23.3	17.3	89	71.5	53.0	149	119.7	88.8	209	167.9	124.5
30	24.1	17.9	90	72.3	53.6	150	120.5	89.4	210	168.7	125.1
31	24.9	18.5	91	73.1	54.2	151	121.3	90.0	211	169.5	125.7
32	25.7	19.1	92	73.9	54.8	152	122.1	90.5	212	170.3	126.3
33	26.5	19.7	93	74.7	55.4	153	122.9	91.1	213	171.1	126.9
34	27.3	20.3	94	75.5	56.0	154	123.7	91.7	214	171.9	127.5
35	28.1	20.8	95	76.3	56.6	155	124.5	92.3	215	172.7	128.1
36	28.9	21.4	96	77.1	57.2	156	125.3	92.9	216	173.5	128.7
37	29.7	22.0	97	77.9	57.8	157	126.1	93.5	217	174.3	129.3
38	30.5	22.6	98	78.7	58.4	158	126.9	94.1	218	175.1	129.9
39	31.3	23.2	99	79.5	59.0	159	127.7	94.7	219	175.9	130.5
40	32.1	23.8	100	80.3	59.6	160	128.5	95.3	220	176.7	131.1
41	32.9	24.4	101	81.1	60.2	161	129.3	95.9	221	177.5	131.6
42	33.7	25.0	102	81.9	60.8	162	130.1	96.5	222	178.3	132.2
43	34.5	25.6	103	82.7	61.4	163	130.9	97.1	223	179.1	132.8
44	35.3	26.2	104	83.5	62.0	164	131.7	97.7	224	179.9	133.4
45	36.1	26.8	105	83.3	62.5	165	132.5	98.3	225	180.7	134.0
46	36.9	27.4	106	85.1	63.1	166	133.3	98.9	226	181.5	134.6
47	37.8	28.0	107	85.9	63.7	167	134.1	99.5	227	182.3	135.2
48	38.6	28.6	108	86.7	64.3	168	134.9	100.1	228	183.1	135.8
49	39.4	29.2	109	87.5	64.9	169	135.7	100.7	229	183.9	136.4
50	40.3	29.8	110	88.4	65.5	170	136.5	101.3	230	184.7	137.0
51	41.0	30.4	111	89.2	66.1	171	137.3	101.9	231	185.5	137.6
52	41.8	31.0	112	90.0	66.7	172	138.2	102.5	232	186.3	138.2
53	42.6	31.6	113	90.8	67.3	173	139.0	103.1	233	187.1	138.8
54	43.4	32.2	114	91.6	67.9	174	139.8	103.7	234	188.0	139.4
55	44.2	32.8	115	92.4	68.5	175	140.6	104.2	235	188.8	140.0
56	45.0	33.4	116	93.2	69.1	176	141.4	104.8	236	189.6	140.6
57	45.8	34.0	117	94.0	69.7	177	142.2	105.4	237	190.4	141.2
58	46.6	34.6	118	94.8	70.3	178	143.0	106.0	238	191.2	141.8
59	47.4	35.2	119	95.6	70.9	179	143.8	106.6	239	192.0	142.4
60	48.2	35.7	120	96.0	71.5	180	144.6	107.2	240	192.8	143.0
Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.

For 4¾ Points.

For 3½ Point.

Dist.	D. Lat	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat	Dep.	Dist.	D. Lat.	Dep.
1	0.8	0.6	61	47.2	38.7	121	93.5	76.8	181	139.9	114.8
2	1.5	1.3	62	47.9	39.3	122	94.3	77.4	182	140.7	115.5
3	2.3	1.9	63	48.7	40.0	123	95.1	78.0	183	141.5	116.1
4	3.1	2.5	64	49.5	40.6	124	95.9	78.7	184	142.2	116.7
5	3.9	3.2	65	50.2	41.2	125	96.6	79.3	185	143.0	117.4
6	4.6	3.8	66	51.0	41.9	126	97.4	79.9	186	143.8	118.0
7	5.4	4.4	67	51.8	42.5	127	98.2	80.6	187	144.6	118.6
8	6.2	5.1	68	52.6	43.1	128	98.9	81.2	188	145.3	119.3
9	7.0	5.7	69	53.3	43.8	129	99.7	81.8	189	146.1	119.9
10	7.7	6.3	70	54.1	44.4	130	100.5	82.5	190	146.9	120.5
11	8.5	7.0	71	54.9	45.0	131	101.3	83.1	191	147.6	121.2
12	9.3	7.6	72	55.7	45.7	132	102.0	83.7	192	148.4	121.8
13	10.0	8.2	73	56.4	46.3	133	102.8	84.4	193	149.2	122.4
14	10.8	8.9	74	57.2	46.9	134	103.6	85.0	194	150.0	123.1
15	11.6	9.5	75	58.0	47.6	135	104.4	85.6	195	150.7	123.7
16	12.4	10.2	76	58.7	48.2	136	105.1	86.3	196	151.5	124.3
17	13.1	10.8	77	59.5	48.8	137	105.9	86.9	197	152.3	125.0
18	13.9	11.4	78	60.3	49.5	138	106.7	87.5	198	153.1	125.6
19	14.7	12.1	79	61.1	50.1	139	107.4	88.2	199	153.8	126.2
20	15.5	12.7	80	61.8	50.8	140	108.2	88.8	200	154.6	126.9
21	16.2	13.3	81	62.6	51.4	141	109.0	89.4	201	155.4	127.5
22	17.0	14.0	82	63.4	52.0	142	109.8	90.1	202	156.1	128.1
23	17.8	14.6	83	64.2	52.7	143	110.5	90.7	203	156.9	128.8
24	18.6	15.2	84	64.9	53.3	144	111.3	91.4	204	157.7	129.4
25	19.3	15.9	85	65.7	53.9	145	112.1	92.0	205	158.5	130.1
26	20.1	16.5	86	66.5	54.6	146	112.9	92.6	206	159.2	130.7
27	20.9	17.1	87	67.[illegible]	55.2	147	113.6	93.3	207	160.0	131.3
28	21.6	17.8	88	68.0	55.8	148	114.4	93.9	208	160.8	132.0
29	22.4	18.4	89	68.8	56.5	149	115.2	94.5	209	161.6	132.6
30	23.2	19.0	90	69.6	57.1	150	116.0	95.2	210	162.3	133.2
31	24.0	19.7	91	70.3	57.7	151	116.7	95.8	211	163.1	133.9
32	24.7	20.3	92	71.1	58.4	152	117.5	96.4	212	163.9	134.5
33	25.5	20.9	93	71.9	59.0	153	118.3	97.1	213	164.7	135.1
34	26.3	21.6	94	72.7	59.6	154	119.0	97.7	214	165.4	155.8
35	27.1	22.2	95	73.4	60.3	155	119.8	98.3	215	166.2	136.4
36	27.8	22.8	96	74.2	60.9	156	120.6	99.0	216	167.0	137.0
37	28.6	23.5	97	75.0	61.5	157	121.4	99.6	217	167.7	137.7
38	29.4	24.1	98	75.8	62.2	158	122.1	100.2	218	168.5	138.3
39	30.1	24.7	99	76.5	62.8	159	122.9	100.9	219	169.3	138.9
40	30.9	25.4	100	77.3	63.4	160	123.7	101.5	220	170.1	139.6
41	31.7	26.0	101	78.1	64.1	161	124.5	102.1	221	170.8	140.2
42	32.5	26.6	102	78.8	64.7	162	125.2	102.8	222	171.6	140.8
43	33.2	27.3	103	79.6	65.3	163	126.0	103.4	223	172.4	141.5
44	34.0	27.9	104	80.4	66.0	164	126.8	104.0	224	173.2	142.1
45	34.8	28.5	105	81.2	66.6	165	127.5	104.7	225	173.9	142.7
46	35.6	29.2	106	81.9	67.2	166	128.3	105.3	226	174.7	143.4
47	36.3	29.8	107	82.7	67.9	167	129.1	105.9	227	175.5	144.0
48	37.1	30.5	108	83.5	68.5	168	129.9	106.6	228	176.2	144.6
49	37.9	31.1	109	84.3	69.1	169	130.6	107.2	229	177.0	145.3
50	38.7	31.7	110	85.0	69.8	170	131.4	107.8	230	177.8	145.9
51	39.4	32.4	111	85.8	70.4	171	132.2	108.5	231	178.6	146.5
52	40.2	33.0	112	86.6	71.1	172	133.0	109.1	232	179.3	147.2
53	41.0	33.6	113	87.5	71.7	173	133.7	109.8	233	180.1	147.8
54	41.7	34.3	114	88.1	72.3	174	134.5	110.4	234	180.9	148.4
55	42.5	34.9	115	88.9	73.0	175	135.3	111.0	235	181.7	149.1
56	43.3	35.5	116	89.7	73.6	176	136.0	111.7	236	182.4	149.7
57	44.1	36.2	117	90.4	74.2	177	136.8	112.3	237	183.2	150.4
58	44.8	36.8	118	91.2	74.9	178	137.6	112.9	238	184.0	151.0
59	45.6	37.4	119	92.0	75.5	179	138.4	113.6	239	184.7	151.6
60	46.4	38.1	120	92.8	76.1	180	139.1	114.2	240	185.5	152.3
Dist.	Dep.	D.Lat	Dist.	Dep	D.Lat	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.

For 4½ Points.

TABLE I.—*Continued.*

Traverse Table to Points and Quarters of the Compass.

For 3¾ Points.											
Dist.	D.Lat	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	0.7	0.7	61	45.2	41.0	121	89.7	81.3	181	134.1	121.6
2	1.5	1.3	62	45.9	41.6	122	90.4	81.9	182	134.9	122.2
3	2.2	2.0	63	46.7	42.3	123	91.1	82.6	183	135.6	122.9
4	3.0	2.7	64	47.4	43.0	124	91.9	83.3	184	136.3	123.6
5	3.7	3.4	65	48.2	43.7	125	92.6	83.9	185	137.1	124.2
6	4.4	4.0	66	48.9	44.3	126	93.4	84.6	186	137.8	124.9
7	5.2	4.7	67	49.6	45.0	127	94.1	85.3	187	138.6	125.6
8	5.9	5.4	68	50.4	45.7	128	94.8	86.0	188	139.3	126.3
9	6.7	6.0	69	51.1	46.3	129	95.6	86.6	189	140.0	126.9
10	7.4	6.7	70	51.9	47.0	130	96.3	87.3	190	140.8	127.6
11	8.2	7.4	71	52.6	47.7	131	97.1	88.0	191	141.5	128.3
12	8.9	8.1	72	53.3	48.4	132	97.8	88.6	192	142.3	128.9
13	9.6	8.7	73	54.1	49.0	133	98.5	89.3	193	143.0	129.6
14	10.4	9.4	74	54.3	49.7	134	99.3	90.0	194	143.7	130.3
15	11.1	10.1	75	55.6	50.4	135	100.0	90.7	195	144.5	131.0
16	11.9	10.7	76	56.3	51.0	136	100.8	91.8	196	145.2	131.6
17	12.6	11.4	77	57.1	51.7	137	101.5	92.0	197	146.0	132.3
18	13.3	12.1	78	57.8	52.4	138	102.3	92.7	198	146.7	133.0
19	14.1	12.8	79	58.5	53.1	139	103.0	93.3	199	147.4	133.6
20	14.8	13.4	80	59.3	53.7	140	103.7	94.0	200	148.2	134.3
21	15.6	14.1	81	60.0	54.4	141	104.5	94.7	201	148.9	135.0
22	16.3	14.8	82	60.8	55.1	142	105.2	95.4	202	149.7	135.7
23	17.0	15.4	83	61.5	55.7	143	106.0	96.0	203	150.4	136.3
24	17.8	16.1	84	62.2	56.4	144	106.7	96.7	204	151.2	137.0
25	18.5	16.8	85	63.0	57.1	145	107.4	97.4	205	151.9	137.7
26	19.3	17.5	86	63.7	57.8	146	108.2	98.0	206	152.6	138.3
27	20.0	18.1	87	64.5	58.4	147	108.9	98.7	207	153.4	139.0
28	20.7	18.8	88	65.2	59.1	148	109.7	99.4	208	154.1	139.7
29	21.5	19.5	89	65.9	59.8	149	110.4	100.1	209	154.9	140.4
30	22.2	20.1	90	66.7	60.4	150	111.1	100.7	210	155.6	141.0
31	23.0	20.8	91	67.4	61.1	151	111.9	101.4	211	156.3	141.7
32	23.7	21.5	92	68.2	61.8	152	112.6	102.1	212	157.1	142.4
33	24.5	22.2	93	68.9	62.5	153	113.4	102.7	213	157.8	143.0
34	25.2	22.8	94	69.6	63.1	154	114.1	103.4	214	158.6	143.7
35	25.9	23.5	95	70.4	63.8	155	114.8	104.1	215	159.3	144.4
36	26.7	24.2	96	71.1	64.5	156	115.6	104.8	216	160.0	145.1
37	27.4	24.8	97	71.9	65.1	157	116.3	105.4	217	160.8	145.7
38	28.2	25.5	98	72.6	65.8	158	117.1	106.1	218	161.5	146.4
39	28.9	26.2	99	73.4	66.5	159	117.8	106.8	219	162.3	147.1
40	29.6	26.9	100	74.1	67.2	160	118.6	107.4	220	163.0	147.7
41	30.4	27.5	101	74.8	67.8	161	119.3	108.1	221	163.8	148.4
42	31.1	28.2	102	75.6	68.5	162	120.0	108.8	222	164.5	149.1
43	31.9	28.9	103	76.3	69.2	163	120.8	109.5	223	165.2	149.8
44	32.6	29.5	104	77.1	69.8	164	121.5	110.1	224	166.0	150.4
45	33.3	30.2	105	77.8	70.5	165	122.3	110.8	225	166.7	151.1
46	34.1	30.9	106	78.5	71.2	166	123.0	111.5	226	167.5	151.8
47	34.8	31.6	107	79.3	71.9	167	123.7	112.2	227	168.2	152.4
48	35.6	32.2	108	80.0	72.5	168	124.5	112.8	228	168.9	153.1
49	36.3	32.9	109	80.8	73.2	169	125.2	113.5	229	169.7	153.8
50	37.0	33.6	110	81.5	73.9	170	126.0	114.2	230	170.4	154.5
51	37.8	34.2	111	82.2	74.5	171	126.7	114.8	231	171.2	155.1
52	38.5	34.9	112	83.0	75.2	172	127.4	115.5	232	171.9	155.8
53	39.3	35.6	113	83.7	75.9	173	128.2	116.2	233	172.6	156.5
54	40.0	36.3	114	84.5	76.6	174	128.9	116.9	234	173.4	157.1
55	40.8	36.9	115	85.2	77.2	175	129.7	117.5	235	174.1	157.8
56	41.5	37.6	116	86.0	77.9	176	130.4	118.2	236	174.9	158.5
57	42.2	38.3	117	86.7	78.6	177	131.1	118.9	237	175.6	159.2
58	43.0	39.0	118	87.4	79.2	178	131.9	119.5	238	176.3	159.8
59	43.7	39.6	119	88.2	79.9	179	132.6	120.2	239	177.1	160.5
60	44.5	40.3	120	88.9	80.6	180	133.4	120.9	240	177.8	161.6
Dist.	Dep.	D.Lat	Dist.	Dep.	D.Lat	Dist.	Dep.	D. Lat.	Dist.	Dep.	D. Lat.
For 4¼ Points.											

For 4 Points.											
Dist.	D. Lat	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.	Dist.	D. Lat.	Dep.
1	0.7	0.7	61	43.1	43.1	121	85.6	85.6	181	128.0	128.0
2	1.4	1.4	62	43.8	43.8	122	86.3	86.3	182	128.7	128.7
3	2.1	2.1	63	44.5	44.5	123	87.0	87.0	183	129.4	129.4
4	2.8	2.8	64	45.3	45.3	124	87.7	87.7	184	130.1	130.1
5	3.5	3.5	65	46.0	46.0	125	88.4	88.4	185	130.8	130.8
6	4.2	4.2	66	46.7	46.7	126	89.1	89.1	186	131.5	131.5
7	4.9	4.9	67	47.4	47.4	127	89.8	89.8	187	132.2	132.2
8	5.7	5.7	68	48.1	48.1	128	90.5	90.5	188	132.9	132.9
9	6.4	6.4	69	48.8	48.8	129	91.2	91.2	189	133.6	133.6
10	7.1	7.1	70	49.5	49.5	130	91.9	91.9	190	134.4	134.4
11	7.8	7.8	71	50.2	50.2	131	92.6	92.6	191	135.1	135.1
12	8.5	8.5	72	50.9	50.9	132	93.3	93.3	192	135.8	135.8
13	9.2	9.2	73	51.6	51.6	133	94.0	94.0	193	136.5	136.5
14	9.9	9.9	74	52.3	52.3	134	94.8	94.8	194	137.2	137.2
15	10.6	10.6	75	53.0	53.0	135	95.5	95.5	195	137.9	137.9
16	11.3	11.3	76	53.7	53.7	136	96.2	96.2	196	138.6	138.6
17	12.0	12.0	77	54.4	54.4	137	96.9	96.9	197	139.3	139.3
18	12.7	12.7	78	55.2	55.2	138	97.6	97.6	198	140.0	140.0
19	13.4	13.4	79	55.9	55.9	139	98.3	98.3	199	140.7	140.7
20	14.1	14.1	80	56.6	56.6	140	99.0	99.0	200	141.4	141.4
21	14.8	14.8	81	57.3	57.3	141	99.7	99.7	201	142.1	142.1
22	15.6	15.6	82	58.0	58.0	142	100.4	100.4	202	142.8	142.8
23	16.3	16.3	83	58.7	58.7	143	101.1	101.1	203	143.5	143.5
24	17.0	17.0	84	59.4	59.4	144	101.8	101.8	204	144.2	144.2
25	17.7	17.7	85	60.1	60.1	145	102.5	102.5	205	145.0	145.0
26	18.4	18.4	86	60.8	60.8	146	103.2	103.2	206	145.7	145.7
27	19.1	19.1	87	61.5	61.5	147	103.9	103.9	207	146.4	146.4
28	19.8	19.8	88	62.2	62.2	148	104.7	104.7	208	147.1	147.1
29	20.5	20.5	89	62.9	62.9	149	105.4	105.4	209	147.8	147.8
30	21.2	21.2	90	63.6	63.6	150	106.1	106.1	210	148.5	148.5
31	21.9	21.9	91	64.5	64.3	151	106.8	106.8	211	149.2	149.2
32	22.6	22.6	92	65.1	65.1	152	107.5	107.5	212	149.9	149.9
33	23.3	23.3	93	65.8	65.8	153	108.2	108.2	213	150.6	150.6
34	24.0	24.0	94	66.5	66.5	154	108.9	108.9	214	151.3	151.3
35	24.7	24.7	95	67.2	67.2	155	109.6	109.6	215	152.0	152.0
36	25.5	25.5	96	67.9	67.9	156	110.3	110.3	216	152.7	152.7
37	26.2	26.2	97	68.6	68.6	157	111.0	111.0	217	153.4	153.4
38	26.9	26.9	98	69.3	69.3	158	111.7	111.7	218	154.1	154.1
39	27.6	27.6	99	70.0	70.0	159	112.4	112.4	219	154.9	154.9
40	28.3	28.3	100	70.7	70.7	160	113.1	113.1	220	155.6	155.6
41	29.0	29.0	101	71.4	71.4	161	113.8	113.8	221	156.3	156.3
42	29.7	29.7	102	72.1	72.1	162	114.6	114.6	222	157.0	157.0
43	30.4	30.4	103	72.8	72.8	163	115.3	115.3	223	157.7	157.7
44	31.1	31.1	104	73.5	73.5	164	116.0	116.0	224	158.4	158.4
45	31.8	31.8	105	74.2	74.2	165	116.7	116.7	225	159.1	159.1
46	32.5	32.5	106	75.0	75.0	166	117.4	117.4	226	159.8	159.8
47	33.2	33.2	107	75.7	75.7	167	118.1	118.1	227	160.5	160.5
48	33.9	33.9	108	76.4	76.4	168	118.8	118.8	228	161.2	161.2
49	34.6	34.6	109	77.1	77.1	169	119.5	119.5	229	161.9	161.9
50	35.4	35.4	110	77.8	77.8	170	120.2	120.2	230	162.6	162.6
51	36.1	36.1	111	78.5	78.5	171	120.9	120.9	231	163.3	163.3
52	36.8	36.8	112	79.2	79.2	172	121.6	121.6	232	164.0	164.0
53	37.5	37.5	113	79.9	79.9	173	122.3	122.3	233	164.8	164.8
54	38.2	38.2	114	80.6	80.6	174	123.0	123.0	234	165.5	165.5
55	38.9	38.9	115	81.3	81.3	175	123.7	123.7	235	166.2	166.2
56	39.6	39.6	116	82.0	82.0	176	124.5	124.5	236	166.9	166.9
57	40.3	40.3	117	82.7	82.7	177	125.2	125.2	237	167.6	167.6
58	41.0	41.0	118	83.4	83.4	178	125.9	125.9	238	168.3	168.3
59	41.7	41.7	119	84.1	84.1	179	126.6	126.6	239	169.0	169.0
60	42.4	42.4	120	84.9	84.9	180	127.3	127.3	240	169.7	169.7
Dist.	Dep.	D Lat	Dist.	Dep.	D. Lat	Dist.	Dep.	D Lat.	Dist.	Dep.	D. Lat.
For 4 Points.											

TABLE II.

Meridional Parts.

M.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	M.
0	0	60	120	180	240	300	361	421	482	542	603	664	725	787	848	910	973	1035	1
1	1	61	121	181	241	301	362	422	483	543	604	665	726	788	850	911	974	1036	2
2	2	62	122	182	242	302	363	423	484	544	605	666	727	789	851	913	975	1037	3
3	3	63	123	183	243	303	364	424	485	545	606	667	728	790	852	914	976	1038	4
4	4	64	124	184	244	304	365	425	486	546	607	668	729	791	853	915	977	1039	5
5	5	65	125	185	245	305	366	426	487	547	608	669	730	792	854	916	978	1041	6
6	6	66	126	186	246	306	367	427	488	548	609	670	731	793	855	917	979	1042	7
7	7	67	127	187	247	307	368	428	489	549	610	671	732	794	856	918	980	1043	8
8	8	68	128	188	248	308	369	429	490	550	611	672	734	795	857	919	981	1044	9
9	9	69	129	189	249	309	370	430	491	551	612	673	735	796	858	920	982	1045	10
10	10	70	130	190	250	310	371	431	492	552	613	674	736	797	859	921	983	1046	11
11	11	71	131	191	251	311	372	432	493	553	614	675	737	798	860	922	984	1047	12
12	12	72	132	192	252	312	373	433	494	554	615	676	738	799	861	923	985	1048	13
13	13	73	133	193	253	313	374	434	495	555	616	677	739	800	862	924	986	1049	14
14	14	74	134	194	254	314	375	435	496	556	617	678	740	801	863	925	987	1050	15
15	15	75	135	195	255	315	376	436	497	557	618	679	741	802	864	926	988	1051	16
16	16	76	136	196	256	316	377	437	498	558	619	680	742	803	865	927	989	1052	17
17	17	77	137	197	257	317	378	438	499	559	620	681	743	804	856	928	990	1053	18
18	18	78	138	198	258	318	379	439	500	560	621	682	744	805	867	929	991	1054	19
19	19	79	139	199	259	319	380	440	501	561	622	683	745	806	868	930	993	1055	20
20	20	80	140	200	260	320	281	441	502	562	623	684	746	807	869	931	994	1056	21
21	21	81	141	201	261	321	382	442	503	564	624	685	747	808	870	932	995	1057	22
22	22	82	142	202	262	322	383	443	504	565	625	687	748	809	871	933	996	1058	23
23	23	83	143	203	263	323	384	444	505	566	626	688	749	810	872	934	997	1059	24
24	24	84	144	204	264	324	385	445	506	567	627	689	750	811	873	935	998	1060	25
25	25	85	145	205	265	325	386	446	507	568	628	690	751	812	874	936	999	1061	26
26	26	86	146	206	266	326	387	447	508	569	629	691	752	813	875	937	1000	1063	27
27	27	87	147	207	267	327	388	448	509	570	631	692	753	815	876	938	1001	1064	28
28	28	88	148	208	268	328	389	449	510	571	632	693	754	816	877	939	1002	1065	29
29	29	89	149	209	269	330	390	450	511	572	633	694	755	817	878	941	1003	1066	30
30	30	90	150	210	270	331	391	451	512	573	634	695	756	818	879	942	1004	1067	31
31	31	91	151	211	271	332	392	452	513	574	635	696	757	819	880	943	1005	1068	32
32	32	92	152	212	272	333	393	453	514	575	636	697	758	820	882	944	1006	1069	33
33	33	93	153	213	273	334	394	454	515	576	637	698	759	821	883	945	1007	1070	34
34	34	94	154	214	274	335	395	455	516	577	638	699	760	822	884	946	1008	1071	35
35	35	95	155	215	275	336	396	456	517	578	639	700	761	823	885	947	1009	1072	36
36	36	96	156	216	276	337	397	457	518	579	640	701	762	824	886	948	1010	1073	37
37	37	97	157	217	277	338	398	458	519	580	641	702	763	825	887	949	1011	1074	38
38	38	98	158	218	278	339	399	459	520	581	642	703	764	826	888	950	1012	1075	39
39	39	99	159	219	279	340	400	460	521	582	643	704	765	827	889	951	1013	1076	40
40	40	100	160	220	280	341	401	461	522	583	644	705	766	828	890	952	1014	1077	41
41	41	101	161	221	281	342	402	462	523	584	645	706	767	829	891	953	1015	1078	42
42	42	102	162	222	282	343	403	463	524	585	646	707	768	830	892	954	1016	1079	43
43	43	103	163	223	283	344	404	464	525	586	647	708	769	831	893	955	1018	1080	44
44	44	104	164	224	284	345	405	465	526	587	648	709	770	832	894	956	1019	1081	45
45	45	105	165	225	285	346	406	466	527	588	649	710	771	833	895	957	1720	1082	46
46	46	106	166	226	286	347	407	467	528	589	650	711	772	834	896	958	1021	1084	47
47	47	107	167	227	287	348	408	468	529	590	651	712	773	835	897	959	1022	1085	48
48	48	108	168	228	288	349	409	469	530	591	652	713	774	836	898	960	1023	1086	49
49	49	109	169	229	289	350	410	470	531	592	653	714	775	837	899	961	1024	1087	50
50	50	110	170	230	290	351	411	471	532	593	654	715	777	838	900	962	1025	1088	51
51	51	111	171	231	291	352	412	472	533	594	655	716	778	839	901	963	1026	1089	52
52	52	112	172	232	292	353	413	473	534	595	656	717	779	840	902	964	1027	1090	53
53	53	113	173	233	293	354	414	474	535	596	657	718	780	841	903	965	1028	1091	54
54	54	114	174	234	294	355	415	476	536	597	658	719	781	842	904	966	1029	1092	55
55	55	115	175	235	295	356	416	477	537	598	659	720	782	843	905	968	1030	1093	56
56	56	116	176	236	296	357	417	478	538	599	660	721	783	844	906	969	1031	1094	57
57	57	117	177	237	297	358	418	479	539	600	661	722	784	845	907	970	1032	1095	58
58	58	118	178	238	298	359	419	480	540	601	662	723	785	846	908	971	1033	1096	59
59	59	119	179	239	299	360	420	481	541	602	663	724	786	847	909	972	1034	1097	60
M.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	M.

TABLE II.—*Continued.*

Meridional Parts.

M.	18°	19°	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	30°	31°	32°	33°	34°	35°	M.
0	1098	1161	1225	1289	1354	1419	1484	1550	1616	1684	1751	1819	1888	1958	2028	2100	2171	2244	0
1	1099	1163	1226	1290	1355	1420	1485	1551	1618	1685	1752	1821	1890	1959	2030	2101	2173	2246	1
2	1100	1164	1227	1291	1356	1421	1486	1552	1619	1686	1753	1822	1891	1960	2031	2102	2174	2247	2
3	1101	1165	1228	1292	1357	1422	1487	1553	1620	1687	1755	1823	1892	1962	2032	2103	2175	2248	3
4	1102	1166	1229	1293	1358	1423	1488	1554	1621	1688	1756	1824	1993	1963	2033	2104	2176	2249	4
5	1103	1167	1230	1295	1359	1424	1490	1556	1622	1689	1757	1825	1894	1964	2034	2105	2178	2250	5
6	1105	1168	1232	1296	1360	1425	1491	1557	1623	1690	1758	1826	1895	1965	2035	2107	2179	2252	6
7	1106	1169	1233	1297	1361	1426	1492	1558	1624	1691	1759	1827	1896	1966	2037	2108	2180	2253	7
8	1107	1170	1234	1298	1362	1427	1493	1559	1625	1693	1760	1829	1898	1967	2038	2109	2181	2254	8
9	1108	1171	1235	1299	1363	1428	1494	1560	1626	1694	1761	1830	1899	1969	2039	2110	2182	2255	9
10	1109	1172	1236	1300	1364	1430	1495	1561	1628	1695	1762	1831	1900	1970	2040	2111	2184	2257	10
11	1110	1173	1237	1301	1366	1431	1496	1562	1629	1696	1764	1832	1901	1971	2041	2113	2185	2258	11
12	1111	1174	1238	1302	1367	1432	1497	1563	1630	1697	1765	1833	1902	1972	2043	2114	2186	2259	12
13	1112	1175	1239	1303	1368	1433	1498	1564	1631	1698	1766	1834	1903	1973	2044	2115	2187	2260	13
14	1113	1176	1240	1304	1369	1434	1499	1565	1652	1699	1767	1835	1905	1974	2045	2116	2188	2261	14
15	1114	1177	1241	1305	1370	1435	1500	1567	1633	1700	1768	1837	1906	1976	2046	2117	2190	2263	15
16	1115	1178	1242	1306	1371	1436	1502	1568	1634	1701	1769	1838	1907	1977	2047	2119	2191	2264	16
17	1116	1179	1243	1307	1372	1437	1503	1569	1635	1703	1770	1839	1908	1978	2048	2120	2192	2265	17
18	1117	1181	1244	1308	1373	1438	1504	1570	1637	1704	1772	1840	1909	1979	2050	2121	2193	2266	18
19	1118	1182	1245	1310	1374	1439	1505	1571	1638	1705	1773	1841	1910	1980	2051	2122	2194	2268	19
20	1119	1183	1246	1311	1375	1440	1506	1572	1639	1706	1774	1842	1912	1981	2052	2123	2196	2269	20
21	1120	1184	1248	1312	1376	1441	1507	1573	1640	1707	1775	1843	1913	1983	2053	2125	2197	2270	21
22	1121	1185	1249	1313	1377	1443	1508	1574	1641	1708	1776	1845	1914	1984	2054	2126	2198	2271	22
23	1122	1186	1250	1314	1379	1444	1509	1575	1642	1709	1777	1846	1915	1985	2056	2127	2199	2272	23
24	1123	1187	1251	1315	1380	1445	1510	1577	1643	1711	1778	1847	1916	1986	2057	2128	2200	2274	24
25	1125	1188	1252	1316	1381	1446	1511	1578	1644	1712	1780	1848	1917	1987	2058	2129	2202	2275	25
26	1126	1189	1253	1317	1382	1447	1513	1579	1645	1713	1781	1849	1918	1988	2059	2131	2203	2276	26
27	1127	1190	1254	1318	1383	1448	1514	1580	1647	1714	1782	1850	1920	1990	2060	2132	2204	2277	27
28	1128	1191	1255	1319	1384	1449	1515	1581	1648	1715	1783	1852	1921	1991	2061	2133	2205	2279	28
29	1129	1192	1256	1320	1385	1450	1516	1582	1649	1716	1784	1853	1922	1992	2063	2134	2207	2280	29
30	1130	1193	1257	1321	1386	1451	1517	1583	1650	1717	1785	1854	1923	1993	2064	2135	2208	2281	30
31	1131	1194	1258	1322	1387	1452	1518	1584	1651	1718	1786	1855	1924	1994	2065	2137	2209	2282	31
32	1132	1195	1259	1324	1388	1453	1519	1585	1652	1720	1787	1856	1925	1995	2066	2138	2210	2283	32
33	1133	1196	1260	1325	1389	1455	1520	1586	1653	1721	1789	1857	1927	1997	2067	2139	2211	2285	33
34	1134	1198	1261	1326	1390	1456	1521	1588	1654	1722	1790	1858	1928	1998	2069	2140	2213	2286	34
35	1135	1199	1262	1327	1392	1457	1522	1589	1656	1723	1791	1860	1929	1999	2070	2141	2214	2287	35
36	1136	1200	1264	1328	1393	1458	1524	1590	1657	1724	1792	1861	1930	2000	2071	2143	2215	2288	36
37	1137	1201	1265	1329	1394	1459	1525	1591	1658	1725	1793	1862	1931	2001	2072	2144	2216	2290	37
38	1138	1202	1266	1330	1395	1460	1526	1592	1659	1726	1794	1863	1932	2002	2073	2145	2217	2291	38
39	1139	1203	1267	1331	1396	1461	1527	1593	1660	1727	1795	1864	1934	2004	2075	2146	2219	2292	39
40	1140	1204	1268	1332	1397	1462	1528	1594	1661	1729	1797	1865	1935	2005	2076	2147	2220	2293	40
41	1141	1205	1269	1333	1398	1463	1529	1595	1662	1730	1798	1866	1936	2006	2077	2149	2221	2295	41
42	1142	1206	1270	1334	1399	1464	1530	1596	1663	1731	1799	1868	1937	2007	2078	2150	2222	2296	42
43	1144	1207	1271	1335	1400	1465	1531	1598	1664	1732	1800	1869	1938	2008	2079	2151	2224	2297	43
44	1145	1208	1272	1336	1401	1467	1532	1599	1666	1733	1801	1870	1939	2010	2080	2152	2225	2298	44
45	1146	1209	1273	1338	1402	1468	1533	1600	1667	1734	1802	1871	1941	2011	2082	2153	2226	2299	45
46	1147	1210	1274	1339	1403	1469	1535	1601	1668	1735	1803	1872	1942	2012	2083	2155	2227	2301	46
47	1148	1211	1275	1340	1405	1470	1536	1602	1669	1736	1805	1873	1943	2013	2084	2156	2228	2302	47
48	1149	1212	1276	1341	1406	1471	1537	1603	1670	1738	1806	1875	1944	2014	2085	2157	2230	2303	48
49	1150	1213	1277	1342	1407	1472	1538	1604	1671	1739	1807	1876	1945	2015	2086	2158	2231	2304	49
50	1151	1215	1278	1343	1408	1473	1539	1605	1672	1740	1808	1877	1946	2017	2088	2159	2231	2306	50
51	1152	1216	1280	1344	1409	1474	1540	1606	1673	1741	1809	1878	1948	2018	2089	2161	2232	2307	51
52	1153	1217	1281	1345	1410	1475	1541	1608	1675	1742	1810	1879	1949	2019	2090	2162	2233	2308	52
53	1154	1218	1282	1346	1411	1476	1542	1609	1676	1743	1811	1880	1950	2020	2091	2163	2235	2309	53
54	1155	1219	1283	1347	1412	1477	1543	1610	1677	1744	1813	1881	1951	2021	2092	2164	2236	2311	54
55	1156	1220	1284	1348	1413	1479	1544	1611	1678	1746	1814	1883	1952	2022	2094	2165	2237	2312	55
56	1157	1221	1285	1349	1414	1480	1546	1612	1679	1747	1815	1884	1953	2024	2095	2167	2238	2313	56
57	1158	1222	1286	1350	1415	1481	1547	1613	1680	1748	1816	1885	1955	2025	2096	2168	2239	2314	57
58	1159	1223	1287	1352	1416	1482	1548	1614	1681	1749	1817	1886	1956	2026	2097	2169	2242	2316	58
59	1160	1224	1288	1353	1418	1483	1549	1615	1682	1750	1818	1887	1957	2027	2098	2170	2243	2417	59
M.	18°	19°	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	30°	31°	32°	33°	34°	35°	M.

TABLE II.—*Continued.*

Meridional Parts.

M.	36°	37°	38°	39°	40°	41°	42°	43°	44°	45°	46°	47°	48°	49°	50°	51°	52°	53°	M.
0	2318	2393	2468	2545	2623	2702	2782	2863	2946	3030	3116	3203	3292	3382	3474	3569	3665	3764	0
1	2319	2394	2470	2546	2624	2703	2783	2864	2947	3031	3117	3204	3293	3384	3476	3570	3667	3765	1
2	2320	2395	2471	2548	2626	2704	2784	2866	2949	3033	3118	3206	3295	3385	3478	3572	3668	3767	2
3	2322	2396	2472	2549	2627	2706	2786	2867	2950	3034	3120	3207	3296	3387	3479	3574	3670	3769	3
4	2323	2398	2473	2550	2628	2707	2687	2869	2951	3036	3121	3209	3298	3388	3481	3575	3672	3770	4
5	2324	2399	2475	2551	2629	2708	2688	2870	2953	3037	3123	3210	3299	3390	3482	3577	3673	3772	5
6	2325	2400	2476	2553	2631	2710	2790	2871	2955	3038	3124	3212	3301	3391	3484	3578	3675	3774	6
7	2327	2401	2477	2554	2632	2711	2791	2873	2956	3040	3126	3213	3302	3393	3485	3580	3677	3775	7
8	2328	2403	2478	2555	2633	2712	2792	2374	2957	3041	3127	3214	3303	3394	3487	3582	3678	3777	8
9	2329	2404	2480	2557	2634	2714	2794	2875	2958	3043	3129	3216	3305	3396	3488	3583	3680	3779	9
10	2330	2405	2481	2558	2636	2715	2795	2877	2960	3044	3130	3217	3306	3397	3490	3585	3681	3780	10
11	2332	2406	2482	2559	2637	2716	2797	2878	2961	3046	3131	3219	3308	3399	8492	3586	3683	3782	11
12	2333	2408	2484	2560	2638	2718	2798	2880	2963	3047	3133	3220	3309	3400	3493	3588	3685	2784	12
13	2334	2409	2485	2562	2640	2719	2799	2881	2964	3048	3134	3222	3311	3402	3495	3590	3686	3785	13
14	2335	2410	2486	2563	2641	2720	2201	2882	2965	3050	3136	3223	3312	3403	3496	3591	3688	3787	14
15	2337	2411	2487	2564	2642	2722	2802	2884	2967	3051	3137	3225	3314	3405	3498	3593	3690	3789	15
16	2338	2413	2489	2566	2644	2723	2803	2885	2968	3053	3139	3226	3316	3407	3499	3594	3691	3790	16
17	2339	2414	2490	2567	2645	2724	2805	2886	2970	3054	3140	3228	3317	3408	3501	3596	3693	3792	17
18	2340	2415	2491	2568	2646	2726	2806	2888	2971	3055	3142	3229	3319	3410	3503	3598	3695	3794	18
19	2342	2416	2492	2569	2648	2727	2807	2889	2972	3057	3143	3231	3320	3411	3504	3599	3696	3795	19
20	2343	2418	2494	2571	2649	2728	2809	2891	2974	3058	3144	3232	3322	3413	3506	3601	3698	3797	20
21	2344	2419	2495	2572	2650	2729	2810	2892	2975	3060	3146	3234	3323	3414	3507	3602	3699	3799	21
22	2345	2420	2496	2573	2651	2731	2811	2893	2976	3061	3147	3235	3325	3416	3509	3604	3701	3800	22
23	2346	2422	2498	2575	2653	2732	2813	2895	2978	3063	3149	3237	3326	3417	3510	3606	3703	3802	23
24	2348	2423	2499	2576	2654	2733	2814	2896	2979	3064	3150	3238	3328	3419	3512	3607	3704	3804	24
25	2349	2424	2500	2577	2655	2735	2815	2897	2981	3065	3152	3240	3329	3420	3514	3609	3706	3806	25
26	2350	2425	2501	2578	2657	2736	2817	2899	2982	3067	3153	3241	3331	3422	3515	3610	3708	3807	26
27	2351	2427	2503	2580	2658	2737	2818	2900	2983	3068	3155	3242	3332	3423	3517	3612	3709	3809	27
28	2353	2428	2504	2581	2659	2739	2820	2902	2985	3070	3156	3244	3334	3425	3518	3614	3711	3811	28
29	2354	2429	2505	2582	2661	2740	2821	2903	2986	3071	3157	3245	3335	3427	3520	3615	3713	3812	29
30	2355	2430	2506	2584	2662	2742	2822	2904	2988	3073	3159	3247	3337	3428	3521	3617	3714	3814	30
31	2356	2432	2508	2585	2663	2743	2824	2906	2989	3074	3160	3248	3338	3430	3523	3618	3716	3816	31
32	2358	2433	2509	2586	2665	2744	2825	2907	2991	3075	3162	3250	3340	3431	3525	3620	3717	3817	32
33	2359	2434	2510	2588	2666	2646	2826	2908	2992	3077	3163	3251	3341	3433	3526	3622	3719	3819	33
34	2360	2435	2512	2589	2667	2647	2828	2910	2993	3078	3165	3253	3343	3434	3528	3623	3721	3821	34
35	2361	2437	2513	2590	2669	2648	2829	2911	2995	3080	3166	3254	3344	3436	3529	3625	3722	3823	35
36	2363	2438	2514	2591	2670	2750	2830	2913	2996	3081	3168	3256	3346	3437	3531	3626	3724	3824	36
37	2364	2439	2515	2593	2671	2751	2832	2914	2998	3083	3169	3257	3347	8439	3532	3628	3726	3826	37
38	2365	2440	2517	2594	2673	2752	2833	2915	2999	3084	3171	3259	3349	3440	3534	3630	3727	3827	38
39	2366	2442	2518	2595	2674	2754	2834	2917	3000	3085	3172	3260	3350	3442	3536	3631	3729	3829	39
40	2468	2443	2519	2597	2675	2755	2836	2918	3002	3087	3173	3262	3352	3443	3537	3633	3731	3831	40
41	2369	2444	2521	2598	2676	2756	2837	2919	3003	3088	3175	3263	3353	3445	3539	3634	3732	3832	41
42	2370	2445	2522	2599	2678	2758	2839	2921	3005	3090	3176	3265	3355	3447	3540	3636	3734	3834	42
43	2371	2447	2523	2601	2679	2759	2840	2022	3006	3091	3178	3266	3356	3448	3542	3638	3736	3836	43
44	2373	2448	2524	2602	2680	2760	2841	2924	3007	3093	3179	3268	3358	3450	3543	3639	3737	3838	44
45	2374	2449	2526	2603	2682	2762	2843	2925	3009	2094	3181	3269	3359	3451	3545	3641	3739	3839	45
46	2375	2451	2527	2604	2683	2763	2844	2926	3010	3095	3182	3271	3361	3453	3547	3643	3741	3841	46
47	2376	2452	2528	2606	2684	2764	2845	2928	3012	3097	3184	3272	3362	3454	3548	3644	3742	3843	47
48	2378	2453	2530	2607	2686	2766	2847	2929	3013	3098	3185	3274	3364	3456	3550	3646	3744	3844	48
49	2379	2454	2531	2608	2687	2767	2848	2931	3014	3100	3187	3275	3365	3457	3551	3647	3746	3846	49
50	2380	2456	2532	2610	2688	2768	2849	2932	3016	3101	3188	3277	3367	3459	3553	3649	3747	3848	50
51	2381	2457	2533	2611	2690	2770	2851	2933	3017	3103	3190	3278	3368	3460	3555	3651	3749	3849	51
52	2383	2458	2535	2612	2691	2771	2852	2935	3019	3104	3191	3280	3370	3462	3556	3652	3750	3851	52
53	2384	2459	2536	2614	2692	2772	2854	2936	3020	3105	3192	3281	3371	3464	3558	3654	3752	3853	53
54	2385	2461	2537	2615	2694	2774	2855	3937	3021	3107	3194	3283	3373	3465	3559	3655	3754	3854	54
55	2386	2462	2538	2616	2695	2775	2856	2939	3023	3108	3195	3284	3374	3467	3561	3657	5755	3856	55
56	2388	2463	2540	2617	2696	2776	2858	2940	3024	3110	3197	3286	3376	3468	3562	3659	3757	3858	56
57	2889	6464	2541	2619	2698	2778	2859	2942	3026	3111	3198	3287	3378	3470	3564	3660	3759	3860	57
58	2390	2466	2542	2620	2699	2779	2860	2943	3027	3113	3200	3289	3379	3471	3566	3662	3760	3861	58
59	2391	2467	2544	2621	2700	2780	2862	2944	3029	3114	3201	3290	3381	3473	3567	3664	3762	3863	59
M.	36°	37°	38°	39°	40°	41°	42°	43°	44°	45°	46°	47°	48°	49°	50°	51°	52°	53°	M.

TABLE II.—*Continued.*

Meridional Parts.

M.	54°	55°	56°	57°	58°	59°	60°	61°	62°	63°	64°	65°	66°	67°	68°	69°	70°	71°	M.
0	3865	3968	4074	4183	4294	4409	4527	4649	4775	4905	5039	5179	5324	5474	5631	5795	5966	6146	0
1	3866	3970	4076	4184	4296	4411	4529	4651	4777	4907	5042	5181	5326	5477	5633	5797	5969	6149	1
2	3868	3971	4077	4186	4298	4413	4531	4653	4779	4909	5044	5184	5328	5479	5636	5800	5972	6152	2
3	3870	3973	4079	4188	4300	4415	4533	4655	4781	4912	5046	5186	5331	5482	5639	5803	5975	6155	3
4	3871	3975	4081	4190	4302	4417	4535	4657	4784	4914	5049	5188	5333	5484	5642	5806	5978	6158	4
5	3873	3977	4083	4192	4304	4419	4537	4660	4786	4916	5051	5191	5336	5487	5644	5809	5981	6161	5
6	3875	3978	4085	4194	4306	4421	4539	4662	4788	4918	5053	5193	5338	5489	5647	5811	5984	6164	6
7	3877	3980	4086	4195	4308	4423	4541	4664	4790	4920	5055	5195	5341	5492	5650	5814	5986	6167	7
8	3878	3982	4088	4197	4309	4425	4543	4666	4792	4923	5058	5198	5343	5495	5652	5817	5989	6170	8
9	3880	3984	4090	4199	4311	4427	4545	4668	4794	4925	5060	5200	5346	5497	5655	5820	5992	6173	9
10	3882	3985	4092	4201	4313	4429	4547	4670	4796	4927	5062	5203	5348	5500	5658	5823	5995	6177	10
11	3883	3987	4094	4203	4315	4431	4549	4672	4798	4929	5065	5205	5351	5502	5660	5825	5998	6180	11
12	3885	3989	4095	4205	4317	4433	4551	4674	4801	4931	5067	5207	5353	5505	5663	5828	6001	6183	12
13	3887	3991	4097	4207	4319	4434	4553	4676	4803	4934	5069	5210	5356	5507	5666	5831	6004	6186	13
14	3889	3992	4099	4208	4321	4436	4555	4678	4805	4936	5071	5212	5358	5510	5668	5834	6007	6189	14
15	3890	3994	4101	4210	4123	4438	4557	4680	4807	4938	5074	5214	5361	5513	5671	5837	6010	6192	15
16	3892	3996	4103	4212	4125	4440	4559	4682	4809	4940	5076	5217	5363	5515	5674	5839	6013	6195	16
17	3894	3998	4104	4214	4327	4442	4562	1684	4811	4943	5078	5219	5366	5518	5676	5842	6016	6198	17
18	3895	3999	4106	4216	4328	4444	4564	4687	4814	4945	5081	5222	5368	552	5679	5845	6019	6201	18
19	3897	4001	4108	4218	4330	4446	4566	4689	4816	4947	5083	5224	5371	5523	5682	5848	6022	6205	19
20	3899	4003	4110	4220	4332	4448	4568	4691	4818	4949	5085	5226	5373	5526	5685	5851	6025	6208	20
21	3901	1005	4112	4221	4334	4450	4570	4693	4820	4951	5088	5229	5376	5528	5687	5854	6028	6211	21
22	3902	4006	4113	4223	4336	4452	4572	4695	4822	4954	5090	5231	5378	5531	5690	5856	6031	6214	22
23	3904	4008	4115	4225	4338	4454	4574	4697	4824	4956	5092	5234	5380	5533	5693	5859	6034	6217	23
24	3906	4010	4117	4227	4340	4456	4576	4699	4826	4958	5095	5236	5383	5536	5695	5862	6037	6220	24
25	3907	4012	4119	4229	4342	4458	4578	4701	4829	4960	5097	5238	5385	5539	5698	5865	6040	6223	25
26	3909	4014	4121	4231	4344	4460	4580	4703	4831	4963	5099	5241	5388	5541	5701	5868	6043	6226	26
27	3911	4015	4122	4232	4346	4462	4582	4705	4833	4965	5102	5243	5390	5544	5704	5871	6046	6230	27
28	3913	4017	4124	4234	4347	4464	4584	4707	4835	4967	5104	5246	5393	5546	5706	5874	6049	6233	28
29	3914	4019	4126	4236	4349	4466	4586	4710	4837	4969	5106	5248	5395	5549	5709	5876	6052	6236	29
30	3916	4021	4128	4238	4351	4468	4588	4712	4839	4972	5108	5250	5398	5552	5712	5879	6055	6239	30
31	3918	4022	4130	4240	4353	4470	4590	4714	4842	4974	5111	5253	5401	5554	5715	5882	6058	6242	31
32	3919	4024	4132	4242	4355	4472	4592	4716	4844	4976	5113	5255	5403	5557	5717	5885	6061	6235	32
33	3921	4026	4133	4244	4357	4474	4594	4718	4846	4978	5115	5258	5406	5559	5720	5888	6064	6249	33
34	3923	4028	4135	4246	4359	4476	4596	4720	4848	4981	5118	5260	5408	5562	5723	5891	6067	6252	34
35	3925	4029	4137	4247	4361	4478	4598	4722	4850	4983	5120	5263	5411	5565	5725	5894	6070	6255	35
36	3926	4031	4139	4249	4363	4480	4600	4724	4852	4985	5122	5265	5413	5567	5728	5896	6073	6258	36
37	3928	4033	4141	4251	4365	4482	4602	4726	4855	4987	5125	5267	5416	5570	5731	5899	6076	6261	37
38	3930	4035	4142	4253	4367	4484	4604	4728	4857	4990	5127	5270	5418	5573	5734	5902	6079	6264	38
39	3932	4037	4144	4255	4369	4486	4606	4731	4859	4992	5129	5272	5421	5575	5736	5905	6082	6268	39
40	3933	4038	4146	4257	4370	4488	4608	4733	4861	4994	5132	5275	5423	5578	5739	5908	6085	6271	40
41	3935	4040	4148	4259	4372	4490	4610	4735	4863	4996	5134	5277	5426	5580	5742	5911	6088	6274	41
42	3937	4042	4150	4260	4374	4492	4612	4737	4865	4999	5136	5280	5428	5583	5745	5914	6091	6277	42
43	3938	4044	4152	4262	4376	4494	4614	4739	4868	5001	5139	5282	5431	5586	5747	5917	6094	6280	43
44	3940	4045	4153	4264	4378	4495	4616	4741	4870	5003	5141	5284	5433	5588	5750	5919	6097	6283	44
45	3942	4047	4155	4266	4380	4497	4618	4743	4872	5005	5143	5287	5436	5591	5753	5922	6100	6287	45
46	3944	4049	4157	4268	4382	4499	4620	4745	4874	5008	5146	5289	5438	5594	5756	5925	6103	6290	46
47	3945	4051	4159	4270	4384	4501	4623	4747	4876	5010	5148	5292	5441	5596	5758	5928	6106	6293	47
48	3947	4052	4161	4272	4386	4503	4625	4750	4879	5012	5151	5294	5443	5599	5761	5931	6109	6296	48
49	3949	4054	4162	4274	4388	4505	4627	4752	4881	5014	5153	5297	5446	5602	5764	5934	6112	6299	49
50	3951	4056	4164	4275	4390	4507	4629	4754	4883	5017	5155	5299	5448	5604	5767	5937	6115	6303	50
51	3952	4058	4166	4277	4392	4509	4631	4756	4885	5019	5158	5301	5451	5607	5770	5940	6118	6306	51
52	3954	4060	4168	4279	4394	4511	4633	4758	4887	5021	5160	5304	5454	5610	5772	5943	6121	6309	52
53	3956	4061	4170	4281	4396	4513	4635	4760	4890	5023	5162	5306	5456	5612	5775	5946	6124	6312	53
54	3958	4063	4172	4283	4398	4515	4637	4762	4892	5026	5165	5309	5459	5615	5778	5948	6127	6315	54
55	3959	4065	4173	4285	4399	4517	4639	4764	4894	5028	5167	5311	5461	5617	5781	5951	6130	6319	55
56	3961	4067	4175	4287	4401	4519	4641	4766	4896	5030	5169	5314	5464	5620	5783	5954	6133	6322	56
57	3963	4069	4177	4289	4403	4521	4643	4769	4898	5033	5172	5316	5466	5623	5786	5957	6136	6325	57
58	3964	4070	4179	4291	4405	4523	4645	4771	4901	5035	5174	5319	5469	5625	5789	5960	6140	6328	58
59	3966	4072	4181	4292	4407	4525	4647	4773	4903	5037	5176	5321	5471	5628	5792	5963	6143	6332	59
M.	54°	55°	56°	57°	58°	59°	60°	61°	62°	63°	64°	65°	66°	67°	68°	69°	70°	71°	M.

TABLE II.—*Continued.*

Meridional Parts.

M.	72°	73°	74°	75°	76°	77°	78°	79°	80°	81°	82°	83°	84°	85°	86°	87°	88°	89°	M.
0	6335	6534	6746	6970	7210	7467	7745	8046	8375	8739	9145	9606	10137	10765	11533	12522	13917	16300	0
1	6338	6538	6749	6974	7214	7472	7749	8051	8381	8745	9153	9614	10147	10776	11547	12541	13945	16357	1
2	6341	6541	6753	6978	7218	7476	7754	8056	8387	8752	9160	9622	10156	10788	11561	12561	13974	16416	2
3	6345	6545	6757	6982	7222	7481	7759	8061	8393	8758	9167	9631	10166	10799	11576	12580	14004	16476	3
4	6348	6548	6760	6986	7227	7485	7764	8067	8398	8765	9174	9639	10175	10811	11590	12599	14033	16537	4
5	6351	6552	6764	6990	7231	7490	7769	8072	8404	8771	9182	9647	10185	10823	11605	12619	14063	16599	5
6	6354	6555	6768	6994	7235	7494	7774	8077	8410	8778	9189	9655	10195	10834	11620	12639	14093	16662	6
7	6358	6558	6771	6997	7239	7498	7778	8083	3416	8784	9196	9664	10205	10846	11634	12659	14123	16726	7
8	6361	6662	6775	7001	7243	7503	7783	8088	8422	8791	9203	9672	10214	10858	11649	12679	14154	16792	8
9	6364	6565	6779	7005	7247	7507	7788	8093	8427	8797	9211	9680	10224	1087	11664	12699	14185	16858	9
10	6367	6569	6782	7009	7252	7512	7793	8099	8433	8804	9218	9689	10234	10881	11679	12719	14216	16926	10
11	6371	6572	6786	7013	7256	7516	7798	8104	8439	8810	9225	9697	10244	10893	11694	12739	14247	16996	11
12	6374	6576	6790	7017	7260	7521	7803	8109	8445	8817	9233	9706	10254	10905	11709	12759	14279	17067	12
13	6377	6579	6793	7021	7264	7525	7808	8115	8451	8823	9240	9714	10264	10917	11724	12780	14311	17140	13
14	6380	6583	6797	7025	7268	7530	7813	8120	8457	8830	9248	9723	10274	10929	11739	12801	14343	17213	14
15	6384	6586	6801	7029	7273	7535	7817	8125	8463	8836	9255	9731	10284	10941	11755	12821	14376	17289	15
16	6387	6590	6804	7033	7277	7539	7822	8131	8469	8843	9262	9740	10294	10953	11770	12842	14409	17366	16
17	6390	6593	6808	7037	7281	7544	7827	8136	8474	8849	9270	9748	10304	10965	11785	12863	14442	17444	17
18	6394	6597	6812	7041	7285	7548	7832	8141	8480	8856	9277	9757	10314	10978	11801	12885	14475	17526	18
19	6397	6600	6815	7045	7289	7553	7837	8147	8486	8863	9285	9765	10324	10990	11816	12906	14509	17609	19
20	6400	6603	6819	7048	7294	7557	7842	8152	8492	8869	9292	9774	10334	11002	11832	12927	14543	17694	20
21	6403	6607	6823	7052	7298	7562	7847	8158	8498	8876	9300	9783	10344	11014	11848	12949	14578	17781	21
22	6407	6610	6826	7056	7302	7566	7852	8163	8504	8883	9307	9791	10354	11027	11863	12971	14613	17870	22
23	6410	6614	6830	7060	7306	7571	7857	8168	8510	8889	9315	9800	10364	11039	11870	12992	14648	17962	23
24	6413	6617	6834	7064	7311	7576	7862	8174	8516	8896	9322	9809	10374	11052	11895	13014	14684	18056	24
25	6417	6621	6838	7068	7315	7580	7867	8179	8522	8903	9330	9817	10385	11064	11911	13037	14720	18153	25
26	6420	6624	6841	7072	7319	7585	7872	8185	8528	8909	9337	9826	10395	11077	11927	13059	14756	18252	26
27	6423	6628	6845	7076	7323	7589	7877	8190	8534	8916	9345	9835	10405	11089	11943	13081	14793	18355	27
28	6427	6631	6849	7080	7328	7594	7882	8196	8540	8923	9353	9844	10416	11102	11959	13104	14830	18461	28
29	6430	6635	6853	7084	7332	7599	7887	8201	8546	8930	9360	9852	10426	11115	11976	13126	14868	18570	29
30	6433	6639	6856	7088	7336	7603	7892	8207	8552	8936	9368	9861	10437	11127	11992	13149	14906	18683	30
31	6437	6642	6860	7092	7341	7608	7897	8212	8558	8943	9376	9870	10447	11140	12008	13172	14944	18799	31
32	6440	6646	6864	7096	7345	7612	7902	8218	8565	8950	9383	9879	10457	11153	12025	13195	14983	18920	32
33	6443	6649	6868	7100	7349	7617	7907	8223	8571	8957	9391	9888	10468	11166	12041	13219	15022	19045	33
34	6447	6653	6871	7104	7353	7622	7912	8229	8577	8963	9399	9897	10478	11179	12058	13242	15062	19174	34
35	6450	6656	6875	7108	7358	7626	7917	8234	8583	897	9407	9906	10489	11192	12075	13266	15102	19309	35
36	6453	6660	6879	7112	7362	7631	7922	8240	8589	8977	9414	9915	10500	11205	12092	13290	15143	19449	36
37	6457	6663	6883	7116	7366	7636	7927	8245	8595	8984	9422	9924	10510	11218	12109	13314	15184	19596	37
38	6460	6667	6886	7120	7371	7640	7932	8251	8601	8991	9430	9933	10521	11231	12126	13338	15226	19749	38
39	6463	6670	6890	7124	7375	7645	7937	8256	8607	8998	9438	9942	10532	11244	12143	13362	15268	19908	39
40	6467	6674	6894	7128	7379	7650	7942	8262	8614	9005	9445	9951	10543	11257	12160	13387	15310	20076	40
41	6470	6677	6898	7132	7384	7654	7948	8267	8620	9012	9453	9960	10553	11270	12177	13411	15354	20252	41
42	6473	6681	6901	7136	7388	7659	7953	8273	8626	9018	9461	9969	10564	11284	12194	13436	15398	20439	42
43	6477	6685	6905	7140	7392	7664	7958	8279	8632	9025	9469	9978	10575	11297	12212	13461	15442	20635	43
44	6480	6688	6909	7145	7397	7668	7963	8284	8638	9032	9477	9987	10586	11310	12229	13486	15487	20843	44
45	6483	6692	6913	7149	7401	7673	7968	8290	8644	9039	9485	9996	10597	11324	12247	13512	15533	21065	45
46	6487	6695	6917	7153	7406	7678	7973	8295	8651	9046	9493	10005	10608	11338	12265	13537	15579	21302	46
47	6490	6699	6920	7157	7410	7683	7978	8301	8657	9053	9501	10015	10619	11351	12282	13563	15625	21557	47
48	6494	6702	6924	7161	7414	7687	7983	8307	8663	9060	9509	10024	10630	11365	12300	13589	15673	21832	48
49	6497	6706	6928	7165	7419	7692	7989	8312	8669	9067	9517	10033	10641	11378	12318	13615	15721	22132	49
50	6500	6710	6932	7169	7423	7697	7994	8318	8676	9074	9525	10043	10652	11392	12336	13641	15770	22459	50
51	6504	6713	6936	7173	7427	7702	7999	8324	8682	9081	9533	10052	10663	11406	12354	13668	15819	22821	51
52	6507	6717	6940	7177	7432	7706	8004	8329	8688	9088	9541	10061	10674	11420	12373	13694	15869	23226	52
53	6511	6720	6943	7181	7436	7711	8009	8335	8695	9096	9549	10071	10685	11434	12391	13721	15920	23685	53
54	6514	6724	5947	7185	7441	7716	8014	8341	8701	9103	9557	10080	10696	11448	12409	13749	15972	24215	54
55	6517	6728	6951	7189	7445	7721	8020	8347	8707	9110	9565	10089	10708	11462	12428	13776	16025	24842	55
56	6521	6731	6955	7194	7449	7725	8025	8352	8714	9117	9573	10099	10719	11476	12446	13804	16078	25609	56
57	6524	6735	6959	7198	7454	7730	8030	8358	8720	9124	9581	10108	10730	11490	12465	13832	16132	26598	57
58	6528	6738	6963	7202	7458	7735	8035	8364	8726	9131	9589	10118	10742	11504	12484	13860	16187	27992	58
59	6531	6742	6966	7206	7463	7740	8040	8369	8733	9138	9598	10127	10753	11518	12503	13888	16243	30375	59
M.	72°	73°	74°	75°	76°	77°	78°	79°	80°	81°	82°	83°	84°	85°	86°	87°	88°	89°	M.

TABLE III.

Depression of the Horizon.

Height of the eye.	Dip.	Height of the Eye.	Dip.	Height of the Eye.	Dip.
1 feet.	1′0	21 feet.	4.′4	110 feet.	10.′0
2	1.4	22	4 5	120	10.5
3	1.7	23	4 6	130	10.9
4	1.9	24	4 7	140	11.3
5	2.1	25	4.8	150	11 7
6	2.3	26	4.9	160	12 0
7	2.5	28	5.0	170	12 4
8	2.7	30	5.2	180	12 8
9	2 9	35	5.6	190	13.1
10	3.0	40	6.0	200	13.5
11	3.2	45	6.4	210	13 8
12	3.3	50	6.7	220	14.1
13	3 4	55	7.1	230	14.4
14	3 6	60	7.4	240	14.7
15	3.7	65	7.7	250	15.1
16	3.8	70	8.0	260	15.4
17	4 0	75	8.2	270	15.7
18	4.1	80	8 5	280	16.0
19	4.2	90	9 0	290	16.2
20	4.3	100	9.5	300	16 5

TABLE IV.

Dip of the Sea, at different Distances from the Observer.

Dist. of Land in Sea Miles.	Height of the Eye above the Sea in Feet.							
	5	10	15	20	25	30	35	40
0 ¼	11′	22′	34′	45′	56′	68′	79′	90′
0 ½	6	11	17	22	28	34	39	45
0 ¾	4	8	12	15	19	23	27	30
1 0	4	6	9	12	15	17	20	23
1 ¼	3	5	7	9	12	14	16	19
1 ½	3	4	6	8	10	11	14	15
2 0	2	3	5	6	8	10	11	12
2 ½	2	3	5	6	7	8	9	10
3 0	2	3	4	5	6	7	8	8
3 ½	2	3	4	5	6	6	7	7
4 0	2	3	4	4	5	6	7	7
5 0	2	3	4	4	5	5	6	6
6 0	2	3	4	4	5	5	6	6

TABLE V.

Difference between the Meridian Altitude of an Object, and its Altitude one Minute before or after the Time of Transit.

Arg. Lat.	Argument. Declination of the Object, of the same Name with the Latitude.												
	0°	2°	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°
0°	*″	56″.2	28″.	18″.7	14″.0	11″.1	9″.2	7″.9	6″.9	6″.0	5″.4	4″.9	4″.4
2	52.2	*	56.1	28.0	18.6	13.9	11.1	9.2	7.8	6.8	5.9	5.3	4.8
4	28.1	56.1	*	55.8	27.3	18.5	13.8	11.0	9.1	7 7	6.7	5.9	5.2
6	18.7	28.0	55.8	*	55.4	27.5	18.3	13.6	10.8	8 9	7.6	6.6	8 8
8	14.0	18.6	27.8	55.4	*	54 9	27.3	18.1	13.4	10.7	8 8	7.5	6 4
10	11.1	13.9	18.5	27 6	54.9	*	54.2	26.9	17.8	13 2	10.5	8.6	7.3
12	9.2	11.1	13 8	18.3	27.3	54.2	*	53.4	26 5	17.5	13.0	10.3	8.4
14	7.9	9.2	11.0	13.6	18.1	26.9	53.4	*	52.5	26 0	17.1	12.7	9.8
16	6.9	7 8	9.1	10.8	13.4	17 8	26.5	52.5	*	51.4	25.4	16.7	12 4
18	6 0	6.8	7.7	8.9	10 7	13 2	17.5	26.0	51.4	*	50.3	24 8	16.4
20	5.4	5.9	6.7	7.6	8.8	10.5	13.0	17.1	25.4	50.3	*	49.0	24.2
22	4.9	5.3	5.9	6 6	7.5	8.6	10.3	12.6	16.8	24.8	49.0	*	47.7
24	4 4	4.8	5 2	5.8	6.4	7.3	8.4	10.0	12.4	16 3	24.2	47.7	*
26	4.0	4 3	4.7	5.2	5.7	6.3	7.1	8.4	9.8	12.1	15.9	23.5	46.2
28	3 7	4.0	4.3	4 6	5.0	5.5	6.2	6.9	8.0	9.5	11.7	15.4	22.7
30	3.4	3 6	3 9	4.2	4.5	4.9	5.5	6.0	6.8	7.8	9.2	11.3	14 9
32	3.1	3.3	3 5	3 8	4.1	4.4	4 8	5 2	5.8	6 6	7.5	8.9	10.9
34	2.9	3.1	3.3	3 5	3.7	4.0	4.3	4.6	5.1	5.6	6.3	7.3	8.5
36	2 7	2.8	3.0	3.2	3 4	3.6	3.8	4.1	4 5	4.9	5 4	6.1	7.0
38	2.5	2 6	2 8	2.9	3 0	3.2	3.4	3 6	4.0	4.3	4.7	5.2	6.0
40	2 3	2.4	2.6	2.7	2 8	3.0	3 1	3.1	3.6	3.8	4.1	4.5	5.0
42	2 2	2.3	2.4	2 5	2 6	2.7	2.9	3.0	3 1	3.5	3.6	4.0	4 3
44	2.0	2.1	2.2	2 3	2 4	2.5	2.6	2.7	2.9	3.1	3 3	3.5	3.8
46	1.9	2.0	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.8	3.0	3.1	3.3
48	1.8	1 8	1.9	2.0	2 0	2.1	2.2	2.3	2.4	2.5	2.6	2.8	3 0
50	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.1	2.2	2 3	2.4	2.5	2.6
55	1.3	1.3	1.5	1.5	1.5	1.6	1 6	1.7	1.7	1.8	1.9	1.9	2.0
60	1.1	1.1	1.2	1.2	1 2	1.3	1.3	1.3	1.4	1.4	1.4	1.5	1.5
70	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.6	0.9
80	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

TABLE V.—*Continued.*

Difference between the Meridian Altitude of an Object, and its Altitude one Minute before or after the Time of Transit.

Arg. Lat.	Argument. Declination of the Object, of a contrary Name with the Latitude.												
	0°	2°	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°
0°	*″	56″.2	28″.1	18″.7	14″.0	11″.1	9″.2	7″.9	6″.9	6″.0	5″.4	4″.9	4″.4
2	56.2	28.2	18.7	14.0	11.2	9.3	7.9	7.0	6.2	5.5	5.0	4 6	4.1
4	28 1	18 7	14.0	11.2	9.3	8.0	7.0	6.2	5.5	5.0	4.5	4.1	3.8
6	18.7	14.0	11.2	9.3	8.0	6.9	6.1	5.5	4 9	4.5	4 2	3.9	3.6
8	14.0	11.2	9.3	8 0	7.0	6.2	5.6	5.0	4 6	4.2	3 9	3 6	3.4
10	11.1	9.3	8.0	7.0	6.2	5.6	5.0	4.6	3.2	3.9	3.6	3.4	3.2
12	9.2	7 9	7.0	6.2	5.6	5.1	4.6	4.3	3.9	3.7	3 4	3.2	3.0
14	7.9	6.9	6.1	5.5	5.1	4.6	4.2	3.9	3.7	3.4	3.2	3.0	2.8
16	6.9	6.1	5.5	5.0	4.6	4.2	3.9	3.7	3 4	3.2	3.0	2.9	2.7
18	6.0	5.5	4.9	4.6	4.2	3.9	3.6	3.4	3.2	3.0	2 9	2 7	2.6
20	5.4	4.9	4.5	4.2	3.9	3.6	3.4	3.2	3.0	2 9	2.7	2.6	2.4
22	4.9	4.5	4.2	3.9	3.6	3.4	3.2	3.0	2.9	2.7	2.6	2.4	2 3
24	4.4	4.1	3.8	3.6	3.4	3.2	3.0	2.8	2.7	2.6	2.4	2.4	2.2
26	4.0	3.8	3.5	3.3	3 2	3.0	2.8	2.7	2.5	2.4	2.3	2.2	2.1
28	3.7	3.5	3.3	3.1	2.9	2 8	2.6	2.5	2.4	2.3	2.2	2.1	2 0
30	3.4	3.2	3.0	2.9	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0	2.0
32	3.1	3.0	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1 8
34	2.9	2.8	2.6	2.5	2.4	2.3	2.2	2.1	2.0	2.0	1.9	1.8	1.8
36	2 7	2.6	2.5	2.4	2.3	2 2	2.1	2.0	1.9	1.9	1.8	1.7	1.7
38	2.5	2 4	2 3	2.2	2.1	2.1	2.0	1.9	1.8	1.8	1.7	1.7	1.6
40	2.3	2.2	2.2	2.1	2.0	2.0	1.9	1 8	1.8	1.7	1.6	1 6	1.5
42	2 2	2.1	2.0	2.0	1.9	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.5
44	2.0	1.9	1.9	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1 5	1.4	1.4
46	1.9	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.4	1 3
48	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1 4	1.4	1.3	1 3	1.3
50	1.7	1 6	1.6	1.5	1.5	1 4	1.4	1.4	1.3	1.3	1.3	1.2	1.2
55	1.3	1.3	1.3	1.3	1 3	1.2	1.2	1.2	1.2	1.1	1.1	1 1	1.0
60	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
70	0.7	0.7	0.7	0.7	0 7	0.7	0.7	0.7	0.7	0.6			
80	0.4	0.3	0 3	0.3	0.3								

TABLE VI.

To Reduce the numbers in the preceding Table to other given intervals of Time from Noon.

	0′	1′	2′	3′	4′	5′	6′	7′	8′	9′	10′		0′	1′	2′	3′	4′	5′	6′	7′	8′	9′	10′
0″	0.0	1.0	4.0	9.0	16.0	25.0	36.0	49.0	64.0	81.0	100.0	30	0.3	2.3	6.3	12.3	20.3	30.3	42.3	56.3	72.3	90.3	110.3
1	0.0	1.0	4.1	9.1	16.1	25.2	36 2	49.2	64.3	81.3	100.3	31	0.3	2.3	6 3	12.4	20.4	30.4	42.5	56.5	72.5	90.6	110.6
2	0.0	1.1	4.1	9.2	16.2	25.3	36.4	49.5	64.5	81.6	100.7	32	0.3	2.4	6.4	12.5	20 5	30.6	42.7	56.7	72.8	90.9	111.0
3	0.0	1.1	4.2	9.3	16.4	25.5	36.6	49 7	64.8	81.9	101.0	33	0.3	2.4	6.5	12.6	20.7	30 8	42.9	57.0	73.1	91.2	111.3
4	0.0	1.1	4.3	9.4	16.5	25.7	36.8	49.9	65.1	82.2	101.3	34	0.3	2.5	6.6	12 7	20.8	31 0	43.1	57.3	73.4	91.5	111.7
5	0.0	1.2	4.3	9.5	16.7	25.8	37.0	50.2	65.3	82.5	101.7	35	0.3	2.5	6.7	12.8	21.0	31.2	43.3	57.5	73 7	91.8	112.0
6	0.0	1.2	4.4	9.6	16.8	26.0	37.2	50.4	65 6	82.8	102.0	36	0.4	2.6	6 8	13 0	21.2	31.4	43.6	57.8	74.0	92.2	112.4
7	0.0	1.3	4.5	9.7	16.9	26.2	37.4	50.6	65.9	83.1	102.3	37	0.4	2.6	6.9	13.1	21.3	31.5	43.8	58.0	74.3	92.5	112.7
8	0 0	1.3	4.6	9.8	17.1	26.3	37.6	50.9	66.1	83.4	102.7	38	0.4	2.7	6.9	13 2	21.5	31.7	44.0	58.3	74.5	92.8	113.1
9	0.0	1.3	4.6	9.9	17.7	26.5	37.8	51.1	66.4	83.7	103.0	39	0.4	2 7	7.0	13.5	21 6	31 9	44 2	58.5	74.8	93.1	113 4
10	0.0	1.4	4.7	10.0	17.4	26.7	38.0	51.4	66.7	84.0	103.4	40	0.4	2.8	7.1	13 4	21.8	32.1	44.4	58 8	75.1	93.4	113.8
11	0.0	1.4	4.8	10.1	17.5	26.9	38.2	51.6	67.0	84.3	103 7	41	0.5	2.8	7.2	13.6	21.9	32 3	44.7	59.0	75.4	93.8	114.1
12	0.0	1.4	4.8	10.2	17.6	27.0	38.4	51.8	67.2	84.6	104.0	42	0.5	2 9	7.3	13 7	22.1	32.5	44.9	59.3	75.7	94.1	114.5
13	0.0	1.5	4.9	10 3	17.8	27 2	38.6	52.1	67.5	84.9	104.4	43	0 5	2.9	7.4	13.8	22.2	32.7	45.1	59.5	76 0	94.4	114 8
14	0.1	1.5	5.0	10.4	17.9	27.4	38.8	52.3	67 8	85.3	104.7	44	0 5	3.0	7.5	13.9	22.4	32.9	45.3	59.8	76 3	94.7	115 2
15	0.1	1.6	5.1	10.6	18.1	27.6	39 0	52.5	68.1	85.6	105.1	45	0.6	3.1	7.6	14.1	22.6	33.1	45.5	60.0	76.6	95.1	115.6
16	0.1	1.6	5.1	10 7	18 2	27.7	39.3	52.8	68.3	85.9	105.4	46	0.6	3.1	7.7	14.2	22.7	33.3	45.8	60.3	76.8	95.4	115.9
17	0.1	1.6	5 2	10.8	18 3	27.9	39.5	53.1	68.6	86.2	105.7	47	0.6	3 2	7.7	14.3	22.9	33.4	46.0	60.6	77 1	95.7	116.3
18	0.1	1.7	5 3	10.9	18 5	28 1	39 7	53.3	68.9	86.5	106.1	48	0.6	3 2	7.8	14.4	23.0	33.6	46 2	60.8	77.4	96.0	116 6
19	0 1	1 7	5.4	11 0	18.6	28.3	39 9	53.5	69.2	86.8	106.4	49	0 7	3 3	7.9	14.6	23.2	33.8	46 5	61.1	77.7	96.4	117.0
20	0.1	1.8	5.4	11.1	18 8	28 4	40.1	53 8	69.	87.1	106.8	50	0.7	3.4	8.0	14.7	23.4	34.0	46.7	61.4	78.0	96 7	117.4
21	0.1	1.8	5 5	11.2	18.9	28 6	40 3	54.0	69.	87.4	107.1	51	0 7	3.4	8.1	14.8	23.5	34.2	46.9	61 6	78.3	97.0	117.7
22	0.1	1.9	5.6	11.3	19.1	28.8	40.5	54 3	70.0	87.7	107 5	52	0 8	3.5	8.2	15.0	23.7	34.4	47.2	61.9	78 6	97.4	118.1
23	0.1	1.9	5 7	11.4	19.2	29 0	40.7	54.5	70.3	88.0	107.8	53	0.8	3.5	8.3	15.1	23.8	34 6	47.4	62.1	78.9	97.7	118.4
24	0.2	2.0	5 8	11.6	19.4	29.2	41.0	54.8	70.6	88.4	108.2	54	0.8	3.6	8.4	15.2	24.0	34.8	47.6	62.4	79.2	98.0	118.8
25	0.2	2.0	5.8	11.7	19.5	29.3	41.2	55.0	70.8	88.7	108.5	55	0.8	3 7	8.5	15.3	24.2	35.0	47.8	62.7	79.5	98.3	119.2
26	0.2	2.1	5.9	11 8	19.7	29.5	41.4	55.3	71.1	89 0	108.9	56	0.9	3.7	8.6	15.5	24.3	35.2	48.1	62.9	79.8	98.7	119.5
27	0.2	2.1	6 0	11.9	19.8	29.7	41.6	55.5	71.4	89.3	109.2	57	0.9	3 8	8.7	15.6	24.5	35.4	48.3	63.2	80.1	99.0	119.9
28	0.2	2 2	6 1	12 0	19.9	29.9	41.8	55.8	71.7	89.6	109.6	58	0.9	3.9	8.8	15.7	24.7	35.6	48.5	63.5	80.4	99.3	120.3
29	0.2	2.2	6.2	12.1	20.1	30.1	42.0	56.0	72.0	89.9	109.9	59	1.0	3.9	8.9	15.9	24.8	35.8	48.8	63 7	80.7	99.7	120.6

NAVIGATION INLAND.

The subjects treated in this article, including what relates to rivers and lakes, being extremely various, we have considered the term Canal as too limited an expression, and have therefore chosen that of *Inland Navigation*, as more appropriate and comprehensive.

The advantages derived from inland navigation are now so generally known and acknowledged, that the statement of a very few facts seems quite sufficient to show its utility.

1. When bulky articles, or those of great weight, are to be moved with great regularity in a short time, inland navigation is the best mode in which this can be accomplished.

2. Agriculture and manufactures profit equally; and the country at large is, by this means, at all times assured of an equal and ready distribution of food and fuel. By diminishing the number of draught horses also, a greater proportion of the produce of the earth is appropriated to the support of man; and the facility of conveyance affords the means of opening districts which would otherwise remain unimproved.

3. The capital saved in the article of transport is, of course, appropriated to more productive labour. To convey 20 tons upon a narrow canal, the horse and boat generally cost about 100*l.* and require only one man and a boy. To carry the same weight by land, more than 20 such horses are required, and at least 10 men. The land establishment would therefore cost at least ten times the expense of that by the canal, under a proportionably greater tear and wear.

4. Against this saving is to be put only the original proper extra cost of the canal and its appendages, over that of a turnpike road and its bridges and other works. The results may be distinctly ascertained, by considering that the total expense of carriage upon canals is only about one-third of that by land, besides its enabling much larger quantities to be conveyed over the same space in the same time; so that whenever an industrious population has increased to a certain extent, this mode of conveyance has invariably been resorted to.

5. The intimate connection between inland navigation, and irrigation and draining, has likewise operated powerfully in promoting the former, as will be seen in the following treatise.

The banks and shores of rivers and lakes being frequented by men in the earliest stages of society, the hollowed trunk of a tree, or wicker baskets, covered with the hides of animals, formed the boats of the first navigators; and of these rude vessels, the Indian canoe, and river coracle, are true specimens. Between these first simple operations, and the construction of perfect artificial canals, much time must have elapsed, the political state of society must have improved, and various mechanical arts have reached a considerable degree of perfection. The earliest operations of this kind, indeed, commenced by protecting the low lands adjacent to the mouths of great rivers, and by directing the flood waters for the purposes of agriculture; so that the drains first employed were afterwards found to afford the means of inland navigation. It was therefore in the Deltas of the Nile, and the Euphrates, the Great Chinese Rivers, and the Estuaries of the Po and the Rhine, that systems of this kind were first established.

Of Egypt.

Ancient historians, although they have all expressed, in general terms, their admiration of the canals of this country, have conveyed no distinct information respecting their dimensions, shape, or mechanical distribution, and their observations had always more immediate reference to the purposes of agriculture.

The following are the only distinct particulars we have been able to collect, viz. that its navigation consisted of, 1st. The river Nile; 2dly, The artificial canals in Upper and Lower Egypt; and, 3dly, The Great Canal, between the Nile and the Red Sea.

All that regarded this river was so intimately connected with the mythology of the country, as to have religious ceremonies attendant upon all its operations; and we have in their hieroglyphics the shape of the barks anciently employed.

From Cairo, at the top of the Delta, to the Cataracts, where the river ceases to be navigable, the distance is about 600 miles, up a narrow valley, of which about 360 miles above Cairo the mountains are calcareous, and those to the southward of that place are granitic.

The inundations of the Nile arise from heavy rains and melting of snows in Abyssinia, and other mountainous regions situated adjacent to the upper part of its source. Herodotus, in his book Euterpe, states, that in the reign of Mœris, or 500 years before the Trojan War, a rise of eight cubits inundated the Delta, so as to be navigable for boats, excepting the small artificial eminences where the towns stood. In the time of Herodotus 15 or 16 cubits were required; this was also the case in the time of the Roman empire; at present 18 are reckoned the standard of abundance; sometimes the increase is 22 cubits. The increase commences at the summer solstice, and continues to the end of August or September. At the end of November, the river has returned within its natural channels. The greatest breadth of the river is about 2000 feet, its motion three miles per hour; its colour is a dirty red, even in April, May and June, when lowest. The perpendicular rise is one-sixth more at Assouan or Syene, than at Cairo, 360 miles below; and, when the inundation is 27 feet at this latter place, it is only about four feet at Rosetta and Damietta; because in Upper Egypt it is confined between high banks, and in the Delta it spreads over the whole country; at Cairo, the banks, at low Nile, are from 12 to 15 feet high, at Rosetta they are from four to five only.

From the debased state in which Egypt has continued for upwards of two thousand years, we can form but a very indistinct notion of its ancient perfection, when under the management of a powerful and well regulated government; but from the best modern authorities, (especially Major Bryce,) it appears that during the greatest part of the year there is in the Nile a free channel for vessels of 40 tons burthen; and it is only during the lowest state of the river, in May and June, that the navigation is confined to small boats. In Upper Egypt, as far as Siout, the ancient Lycopolis, the channel is clear of rocks. From this place to the Cataracts, the intricacy of the channel, and rapidity of the currents, require the experienced pilots of the country. Norden, in a boat drawing three feet water, made a voyage from Cairo to the Cataracts and back, including various short stoppages, and seven days detention at Assouan, in 97 days; that is, from 18th November to the 23d of February.

Of the canal of Joseph, or rather Jussef, which runs parallel to, and on the western side of the Nile, the construction and purpose seem alike uncertain. For in the map of M. d'Anville, that constructed by the engineers attached to the French army, and the excellent one composed by Arrowsmith, from the information furnished by Major Bryce and other English officers, there are considerable differences as to the extent and direction of this canal, and also in regard to its connections with the river Nile and the lake Berket Keroun, (formerly the lake Mœris). It appears to have been drawn along the skirts of the Desert opposite Memphis, and thence continued along the eastern side of the pyramids of Ghize, and terminated in the western branch of the Nile, towards the eastern extremity of the lake Mareotis, and from thence northward to the ancient Plinthus, or Abouscor, round the Mourgham Point, where the head of a canal and sluice still exists.

With regard to the question, whether in upper Egypt this canal is not the channel of the ancient Nile, which may have formerly passed through the valley of Faioum and River without Water, into the Lybian desert: It is not improbable, that this may have been the case with the whole or a part of the river, and that its northern extremity may have been barred by sands drifting from the westward, thereby turning the whole stream into the eastern or present valley, but leaving for many centuries a part of the ancient course an immense lake, which has itself in course of time been filled up by sands. And the canal Jussef may be the remaining lowest parts of the ancient channel. Thus the great features may have been formed by natural operations; but many of the inferior have no doubt been, in the course of ages, accomplished by human art and industry; for Diodorus Siculus informs us, that Nilus, one of the ancient kings, so much improved the economy of the river, as to have his name given to it, instead of Egyptus, its former appellation.

From the long neglected state of this singular place, added to the changes arising from the great river passing in Lower Egypt over a vast level plain, and the constant operation of the sea and west winds on its coast, the ancient features must have been in general obliterated, and others formerly unknown have made their appearance. Formerly, the waters of the Nile were discharged into the sea by seven mouths, viz. 1st, The Pelusiac, or Bubastic; 2d, Temitic, or Saitic; 3d, Mendescan, or Dylich; 4th, Phanitic, or Bucolic, (near Damietta;) 5th, Sebenitic, or Boorlas; 6th, Bolbetine, (Rosetta;) 7th, Canopus, or Aboukir. At present there are only two mouths, viz. Rosetta and Damietta. The shore of the Delta consists of a succession of shallow lakes, formed apparently by the westerly winds acting upon the sands, when kept in motion by the inundations.

The lake Mareotis, to the south of Alexandria, is connected with the lake Aboukir by a cut 120 yards wide, made by the English in 1801. This latter communicates with the bay of Aboukir by the ancient Canopic mouth, about 300 yards wide, and 7 feet deep. To the eastward is lake Etko, with an entrance from the sea about 200 yards wide, and from 6 to 10 feet deep, and from 2¼ to 7 within the entrance. The Rosetta mouth has from 10 to 3½ feet. Up to Rosetta the bar is not passable one day in four. This branch, when confined within its banks, is not quite half a mile wide: the banks are from 4 to 5 feet high at low water. To the eastward of Rosetta, the lake Boorlas is entered by the ancient Sebenitic mouth, with 7 feet water. It has at all seasons a communication with the interior by the canals Tabane, Gemassac, and Harinen. The Damietta branch is, during the low state of the river, still more imperfect than that of Rosetta. The great lake Menzalech extends from near the eastern banks of the Damietta branch to that of the ancient Pelusiac, and occupies that of the Mendesian and Tanitic. Its greatest length from east to west is 52 miles; its smallest breadth is 14½ miles. It communicates with the sea by the ancient Tanitic and Mendesian branches. The last has 7 feet water. During four months of high water, small vessels pass along the lake to Damietta; at other seasons they discharge at Dybeh. The Tanitic mouth has 6 feet water. It is only navigable 60 days of the Nile's increase. Besides these, another entrance, called False Mouth, has been formed, but the approach is intricate. The canal of Maez, or Moses, enters this great lake to the south-east of the isles of Mathcych, near the ancient Panephysis. This canal proceeds from the upper part of the Damietta branch of the Nile, where it is about 328 yards in breadth. The canal is 164 yards; the depth for six leagues is about 16 feet. After passing Fournigheh, it contracts to 65 yards; the depth remains the same from Samnah to the lake. It is from 65 to 131 yards in breadth, and from 10 to 13 feet in depth. During nine months, the water of the Nile flows into the lake. For the latter three months it reflows towards the country. At full height of the river the largest vessels of the interior have a free navigation; and for the latter part of the season, vessels navigating the lake can make a passage to Cairo in five days.

There are numerous other canals or channels in the eastern side of the Damietta branch; also between it and the Rosetta branch they are in general very imperfect. The Tabane is said to be 90 yards wide, and 7 feet deep, but in dry seasons 2½ feet only. The canal of Mahadic, which falls into the Boorlas canal, is said to be 30 yards wide at high waters of the Nile, and from 4 to 5 feet deep.

Between the Rosetta Nile and Alexandria, the whole shore is occupied by lakes Etho and Aboukir. The latter was formed in 1760 by the breaking of a wall. It now approaches so near the lake Mareotis, as scarcely to leave room for the canal of Alexandria. This celebrated canal leaves the Rosetta Nile near Rhameneh. It passes a little south of Demanhour, (the ancient Hermopolis Parva,) and from thence by the north-east shore of the lake Mareotis to Alexandria. A little west of Rhameneh, a branch passes off to the north-west, as does another between that place and Demanhour. Near the eastern extremity of Mareotis, a branch communicates with that lake. From the memoir of the French engineers Lanoret and Chabrol, we learn, that in approaching Rhameneh, the Rosetta Nile separates into two branches, forming a chain of isles. The eastern arm is most considerable, and remains always navigable; the other has been filled up about 12 years ago, so that it remains dry about 9 months in the year. About 1312 yards below Rhameneh the canal of Alexandria commences. The waters enter by the two mouths, elevated about 9 feet above the lowest waters of the river, and distant about 656 yards from each other. The lowest is the most ancient. It has been abandoned, because the successive repairs had raised the banks so much, that the sails of the barks could not receive the wind. At the commencement the new branch is only 19½ feet in width. It afterwards, at the village of Lemedis, has increased to about 55 yards in breadth, and continues so for 2½ leagues. The banks are here raised about 13 feet above the bottom, and 10 feet above the surface of the ground. This part bears the marks of great antiquity. There are the remains of a wharf and basin. It was here all the productions of the province of Bakhiroh were collected and shipped for the city of Alexandria. For two leagues more there is nothing worth notice. From Gabel the canal for four leagues is 22½ yards of mean breadth, and very regular. At Leloha it is nearly of the same breadth; but the adjacent plain lowers by degrees, until the bottom of the canal is in the same level, and even above it; it again falls under the surface half a league before it reaches Alexandria. After visiting Leloha, the canal widens. For half a league it has from 109 to 273 yards in breadth. The banks are scarcely elevated 6½ feet, and so imperfect, that the water filtrates through them. Near Beda the canal is only 55 yards in breadth. The banks are 23 feet high, and covered with loose sand, which threatens to fill it up. At this place the canal is at a mean distance of 109 yards from the lake Aboukir. It afterwards approaches the western extremity of the lake, and is only separated by a stone wall about 20 feet in thickness. Another wall of 55 yards forms a dyke on the side of the plain.

From the western extremity of the lake it passes over wet marshy ground, covered with a salt crust from 4 to 6 inches in thickness. It then passes through a wood of dates for half a league; and has a number of cisterns on the northern side, which appear of Greek or Roman construction, but much disfigured by modern repairs. In approaching Alexandria, there are numerous trunks of granite columns, and other fragments of Greek architecture. At half a league from the city, the bottom of the canal is a little lower than the surface of the sea, but from this place to the enclosure of the Arabs it has a counter slope. At last the canal, with a breadth of from 22 to 27 yards, turns the base of a small hillock upon which Pompey's Pillar stands. It afterwards becomes very narrow, and terminates in the old port in shape of a drain.

Before the water enters the canal of Alexandria, it has risen, in common seasons, 13 feet above the lowest Nile. The mean depth in the canal, when the water has reached the greatest height, is about two feet. The rise of water is first perceived at Rhameneh between the 10th and 20th July. Towards the middle of August it has reached the bottom of the canal; it takes a month afterwards to reach Alexandria, being 20 leagues, though in a straight line only 15 leagues. The waters reach Alexandria about the 25th September, and as the Nile has begun to decrease at Rhameneh since the 15th of this month, it follows, that the navigation cannot continue longer than 20 to 25 days.

Under the Mamelukes, the commandant of the province encamped on the banks of the canal, from the moment the water began to run until the cisterns of Alexandria were filled. His object was to prevent the Arabs of the Desert, and the inhabitants of the villages, from cutting the banks; also to watch if too great a quantity threatened to destroy any parts of the banks. When the cisterns of Alexandria were full, he went into the city and demanded a verification. They filled a vase with water from the cisterns. This vase was sealed by those who made the verification, and served as an attestation to the commandant at Cairo that the water was good, and the cisterns full.

The French, by cleaning out about 18 inches of mud, passed with small boats to Rhameneh for about six weeks, when the Nile was at its height.

It appears from Strabo and others, that this canal was anciently drawn from the Canopic branch of the Nile, near the city of Chedia, at the distance of about 6 or 8 leagues.

The canal, although at present it passes through ruins and deserts, and has ceased to be navigable, was, not more than 460 years ago, in the midst of the riches of Egypt, and was formerly the channel through which, during the Greek and Roman empires, the productions of Egypt and the eastern world were carried to Alexandria for exportation to Europe.

At Rosetta there was found, at 4 feet under the surface of the ground, a granite table with three inscriptions: 1. Hieroglyphics; 2. Syrian; 3. Greek. The two latter have the same meaning, which is, that Ptolemy Eupator had employed 7½ years to clear out and renew all the canals of Egypt.

With regard to the great canal from the river Nile to the Red Sea, we shall take the sundry authorities as they stand in point of priority of time. 1st, Herodotus (lib. ii.) says, a canal was drawn from the Nile above the city of Bubasto; that it passed around a mountain from the west to the east, and afterwards turned south to the Red Sea. He attributes its commencement to Necos, the son of Psammaticus, 616 B. C., but gives its completion to Darius Hystaspes, 521 B. C. It was four days navigation, and four ships could pass abreast.

2. Aristotle (*Met.* lib. i. ch. 14) says, a king had attempted to draw a canal from the Red Sea to the Nile, but abandoned the work, because the Red Sea was higher than the land of Egypt.

3. Diod. Sicul. (lib. ii.) attributes it to Necos, but says it was completed by Ptolemy Philadelphus, 280 B. C. when it was named the River of Ptolemy; but he makes it communicate with the Pelusiac branch of the Nile.

4. Strabo agrees with Herodotus; says it was 100 cubits in breadth, with depth sufficient to carry large vessels, (lib. i. and xvii.) He adds, that it terminated at the Arabic Gulf, and that in his time the merchants of Alexandria found an outlet from the Nile in the Arabic Gulf, to go to India.

5. Pliny says this canal was begun by Sesostris, or Sesac, (970 B. C.) near Bubasto, (lib. xxvi. ch. 29 and 33.) and went to the Red Sea; that Darius proceeded with it afterwards, and Ptolemy II. after Darius. He adds, that the latter conducted the canal by the bitter fountains, but ceased, having been told that the Red Sea was three cubits higher than the land of Egypt.

6. The Geographer Ptolemy, who lived in the time of Trajan and Hadrian, (*Geog.* lib. iv. c. 5.) calls it Trajan's River.

Omar-ebn-el-Kattab ordered Amrou, who had conquered Egypt, about the year 635, to open the canal from the Nile to Quotzoum, on the Red Sea, to convey the contributions in corn into Arabia. Elkmaim informs us, that it was shut up again by the Caliph Abugia, or Almanzor, in the year 773.

From the before mentioned respectable authorities, we have reason to believe that there has at sundry times been a canal open from the river Nile to the Red Sea, at the bottom of the Gulf of Suez, and that there had been the means of occasionally using it. Whether ships were passed from the canal into the Red Sea does not appear. There might have been a trans-shipping; but it is certain that this route was afterwards abandoned, and the eastern commodities landed at a place under the tropic, named Berenice, about 450 miles south of Suez, whence they were transported 258 Roman miles across the Desert to the city of Coptis, upon the Nile, down which they were carried to Alexandria.

This instrument measured the rise of the Nile; but as the ancient accounts vary from 8 to 18 cubits, some fallacy, or rather misunderstanding, is suspected, since, for more than 2000 years past, little alteration has taken place. But in the course of the many convulsive changes to which the country has been subject, the Nilometer could not well be expected to remain of the same divisions, or even in the same situation. We have no correct account of what passed relating to it during the Persian and Greek invasions, nor indeed until the time of Constantine. This prince prohibited sacrifices in the temple of Serapis, where the Nilometer stood, and removed it into the church. Julian replaced it in the temple of Serapis, where it remained till Theodosius. Until the time of Omar, it had been divided into cubits of 24 digits each; but this was then destroyed, and another placed in the island of Rowda, where the lower 12 cubits were divided into 28 digits each. In the years 714 and 854 this instrument was twice destroyed, and the present one, said to have been put up by the emperor Elmctauakkel. There is one in Upper Egypt, which may have been more exempted from alterations.

Thus we find, that the rise of the inundations, as ascertained by the Nilometers in different eras, must be considered as far from a correct standard of comparison.

China.

This very extensive and singular country, separated from the rest of Asia by inaccessible mountains and deserts, and having a great variety of soil and climate, enables it to maintain a numerous society almost independent of foreign relations. From the patriarchal form of its government, and in consequence of all the land being considered the property of the Emperor, and his decrees pervading his extensive dominions, which comprehend the entire course of numerous large rivers, plains, and deltas, the construction of inland navigations has been greatly facilitated.

This great country descends from the frontier mountains of Thibet and Tartary to the Eastern Ocean, and is traversed by two very large rivers. The most southern, Yang-tse, Kiang-keo, or Son of the Sea, is reckoned about 2000 miles in length, and at Nanking, 100 miles from the sea, it is more than 2½ miles in breadth. The other, named the Yellow River, or Heng-ho-kea, is said to be longer than the former. The branches of those mighty streams are large rivers, and traverse extensive and rich countries. The main streams are sometimes 1000 miles apart, but enter the sea within 100 miles of each other.

The general direction of the Chinese rivers being from west to east, and the chief line of intercourse being north and south, has led to form artificial canals between them. By which means an inland navigation is completed from the capital, at Pekin in the north, to the city of Canton in the southern part of the empire, reckoned a distance of about 920 miles. From this general canal, and the great rivers, branches are carried to almost every town and village of any consequence in the flat countries.

These navigations have arisen by slow degrees, from circumstances connected with the government, and the frequent change of the site of the capital. It is said, that about 246, B. C. the prince Tsin-chi-koang, on account of the wars and works he undertook, and the great consumption of his capital, made his subjects carry, night and day, from place to place, many millions sacks of grain, so that they were made beasts of burden. But that Han, who began to reign in 202, B. C. caused canals to be made to carry rice and other grain from the provinces to the capital, so that all porterage was abolished; but it was not till 86, B. C. that these great works were completed. Between this time and the year 1260, the capital was moved successively into the provinces of Chensi, Chansi, Honan, How-Kouang, and Tche-Kiang, and each of course requiring inland navigation.

Yangte, of the dynasty of Tsin, about 605 of the Christian era, enlarged the old canals, and opened new ones to carry barks from the Yellow River to the Kiang, and thence to the rivers Tsi, Owi, and Han. He received a memoir respecting canals of a *new invention*, and to render rivers navigable; and it is said that 1600 leagues were effected. Some of these canals were faced with stone. Those that went from the coast of the north to that of the south had 40 steps of breadth: those to the coasts of the east and west were less magnificent, but were also bordered with rows of trees. But the boldest measure was, turning the Yellow River into the Gulf of Leao-Tong, about the year 1064.

Youen, or Mangoux, having, about the year 1269, conquered China, fixed the capital at Pekin, caused to be made the canal Yaho, to carry grain to his capital; he was also very tyrannical, and carried on works to keep the conquered people employed.

There is a Chinese history of 40 volumes, respecting the management of the waters. It is all composed of citations and authorities. Tai-tsou, founder of the dynasty of Ming, began to repair the canals in 1369, because the Youens had, during their misfortune, neglected them; he also made others. Yang-lo employed the most learned men of his time, and also his wealth, in making new reservoirs, and water for the canals, the lines of which, when necessary, were changed and improved. In 1647, it is said that the rains of the sixth moon cut the level of Tchang-ho, and caused it to burst out; and that for the ten following years, no such accidents happened; but that towards the termination of the Mings, the laws for supporting canals were neglected, some sluices were damaged, and some parts filled with mud. The before mentioned publication contains a minute history of the management of the waters through that extensive empire during 1800 years.

The inland navigation between Pekin and Canton may be considered under two divisions, 1st, from Pekin, by a tract of about 500 miles to the Yellow River; and 2d, from the latter place to Canton.

The first, named the Imperial Canal, because navigated by the emperor's barks, of which Le Compte reckons about 1000 of 80 tons each. Duhalde states, that this canal has its summit, or point of partition, near the small city Owen-chan-tien, where it is supplied by the small river Owen-ho; two thirds of which passes into the northern portion of the canal, which, after a long course, falls into the River of Pekin, near the city Tient-sing-Oui, in the province of Picholi; it is not continued to Pekin, in order that the porterage may employ the great population of that quarter. The remaining third of the water passes southward by a canal of the Yellow River, at about 25 leagues from the sea, where the river is about a mile wide, and 9 or 10 feet deep; this portion of the canal runs, for many miles, along the sides of lakes and marshes—some of which supply feeders.

As the point of partition is elevated considerably above the northern termination in the Pekin river, and the southern in the Yellow River, the water passing in each direction, and of course the navigation is regulated by a sort of sluices, the Chinese call *cha*, and the French *pertuis*, which will be described in another part of this article. The water, in dry seasons, is only five or six feet in depth, and sometimes only three, to pass the imperial barks. Of these chas there are 45 in number. Where the fall is small, vessels pass easily and with safety; but at one named Tien-fo-cha, that is, the Queen of Heaven, there is, on account of its height, very considerable difficulty. The sides of the canal are lined with stone in only a few places, in sandy ground and near lakes. Between the Yellow River and the river Kiang, considerable difficulties have been encountered, where enormous dykes are required along the side of the great lake and the river Kuai-ho; the works near Hoainganfou are the most perfect in the canal; near Yantcheou they form quays to the city.

2*d* division, From the great river Kiang, which is here 2½ miles in breadth, the navigation continues southward by two separate tracks, both of which unite at the southern extremity of the great lake Poyan-hou, one is by passing up the great river, entering at the northern extremity of the said lake, and passing along it; the other is by means of canals and smaller rivers. This canal leaves the bank of the great river Kiang at the city Tching Kiang, proceeds by Tching Tcheou, and between a great lake on the west, and two smaller ones on the east, to the great city of Hang-Tcheou, and past the cities of Yan-tcheou, Kiou-tcheou, and Koang-sin to Nan-tchang, a little from the northern extremity of the great lake Poyan Hou. From this point the navigation proceeds up the river Kan Kiang to the base of the great ridge of the mountains Miolin or Mielin, which divides the provinces of Kiamese and Canton; here there is a carrying place of about 30 miles, across rugged mountains, to the river Pekiang, which runs between Nangan and Nang Yong, where the navigation again commences, and proceeds by Cha-tcheou down to Canton. There is still another track, by which this carrying place is avoided; this is by passing up the great river Kiang to the great lake Tong-ting-hou, thence proceeding up a river which falls into it, until it passes the city Yong tcheou, from whence there is an artificial navigation formed by the water collected from the mountains, to a river which falls in the sea of Canton; but this is circuitous, and frequently deficient in depth. In this artificial part there are sundry Cha's, but instead of being like those in the Imperial Canal, they are made with earth and piles, and closed with mats. It required about three months to go from Pekin to Canton by water.

In both the north and south divisions of this extensive navigation, from each side of the grand canal, many smaller ones branch off to considerable cities, and even villages, and not unfrequently pass around them. The banks are here frequently lined with freestone, having sluices, by which water is drawn off for the purpose of irrigation, or for large reservoirs for the use of cities, &c.

The bark in which Le Compte travelled from Nimpo was 70 feet in length, 16 feet broad, and 10 or 12 feet high, and contained a hall, four rooms, and a kitchen. The great plains are very favourable for navigation, but the southern portions toward the mountains, and along the rivers, are said to be difficult and tedious; and the same on the southern side of the mountains towards Canton.

In some parts of China, when two portions of the same canal are upon different levels, varying, in some instances, about 15 feet, the boats are passed from the one to the other by a double glacis of stone, formed of two inclined planes, extended down to the bottom of the canal, which will be described in another part of this article; but there are none of these upon the Imperial Canal, where the emperor's barks navigate.

Le Compte states, that from Nanking, by means of the Yellow River, and sundry canals branching from it, that they navigate westward to the mountains of Tartary, for above 1000 miles; but that in this distance there are many inclined planes, &c., worked by numerous bodies of men.

From the foregoing information, it appears that the progress of inland navigation in China is in perfect unison with the general character of that nation; that is to say, by dint of great labour, an extensive water conveyance has been established, but the different levels being only connected in the Imperial Canal by cha's or shines, and in all the others by means of rude inclined planes, with torrents of water running down them, and up which the vessels are dragged by manual labour; both operations clumsy and incommodious when compared with the facility and security of the European Lock. The Chinese have, therefore, evidently in this leading feature of canal making, as in other matters where mechanical science is concerned, stopped at a very moderate degree of perfection.

India.

On the eastern side of the old continent, and next in importance to China, are those extensive countries, which are traversed by the great rivers Burrampooter, Ganges, and Indus, and known to the western world by the name of Hindostan, or the East Indies.

The eastern commodities were anciently conveyed to the west by land routes, varying, as victorious princes moved their capital into favourite provinces, the principal depots being successively at Oude, Canouge, Delhi, Agra, and Lahore, the traffic being chiefly in silks, jewels, spiceries, and other articles of luxury, whose weight and bulk were very small when compared to their value. They were conveyed with facility by means of animals, styled the ships of the desert; the motives for creating artificially a water conveyance, did not therefore exist. The fertility of their rich plains, added to the religion and habits of the people, have constantly tended to foster habits of indolence, and even the hardy mountaineers, after conquering the country, have repeatedly been enervated. Since modern Europeans have been established in that quarter, they have hitherto been either contending with each other for superiority, or engaged in subduing the native states, and carrying the produce of their labours by sea to markets in the west, and it is not probable that projects for internal improvements will be carried to much extent, until a powerful, enlightened, and permanent government has been established in India.

Although little has been accomplished by human art, yet there has always been a very extensive inland navigation by means of the before-mentioned great rivers, of which we shall give a short account in the following order: 1. The Indus, with its branches and canals; 2. The Ganges and Burrampooter; 3. The rivers south of the Ganges; and 4. The rivers between the Burrampooter and China.

The length of the Indus is reckoned at 1350 miles. Its source is near the eastern limits of the mountains of Thibet, on the opposite side of the same ridge from whence the Ganges proceeds. After traversing little Thibet, it crosses the chain of mountains named the Hindoo Cook or Kok; after receiving the river Cabul at Attock, it passes the salt range at Callabaugh. After passing Attock, its course, with great bendings, is a little west of south to Moultan, where it receives the Punjab rivers; thence its direction is still more west of south to Tatta, where it divides into several streams; and, according to Major Rennel, the latitude of Lany Bundu, (which, during the last century, was the principal channel of the Indus,) is 24° 44′ north; that the Delta is 150 miles in length along the coast; that about 115 miles from the sea, in a straight line, it divides into two branches, of which that to the west is the largest: that after proceeding about 50 miles in a South-west direction, this branch again divides into two, the smaller passing W.S.W. to Lany Bundu and Darroway; the larger taking the name of Ritchel, runs to a town of that name on the sea coast. The city of Tatta, the capital of Sinda, is within the inferior Delta, about five miles below its upper angle. The lower part of this Delta is much intersected by creeks; it has no trees, but is covered with brushwood, and consists chiefly of swamps and muddy lakes.

The tide being visible only 60 or 65 miles from the coast, indicates a considerable declivity. In the mouths of the rivers the bores are high: just above the tideway the Ritchel is said to be about a mile in width, at the city of Tatta half a mile. The velocity of the current is about four miles per hour in the dry season. The Indus and its branches afford a free navigation for vessels of 200 tons from Tatta to Moultan and Lahore: Moultan and Allahabad are about the same distance from the sea, that is, about 850 miles by the rivers. Captain Hamilton says, that boats come from Lahore to Tatta in 12 days.

Besides these extensive river navigations, it was in the district called the Punjab, or country of five rivers, that the only artificial canals of any extent in India were constructed, chiefly by Feroze III. about 1351, who persevered in making these improvements for 37 years. The country between Delhi, upon the Jumna (a branch of the Ganges) and the Punjab on the Indus, being frequently without water, this prince undertook to furnish a supply for the purposes of agriculture and inland navigation; he therefore built the city of Hipai Ferozeh, about 100 miles west of Delhi, and caused two canals to be drawn to it. He had previously made a canal from the Jumnah, near the northern hills, to Sufidoon, a royal hunting place; this canal was full 60 miles in length; it passed by Canawl and Ioglickpoor; it was about four yards in breadth; he afterwards extended it to Hipai, his new city, when it was altogether 114 miles in length. About 1626, Shah Ischan made clear out that part which reaches from the hills to Sufidoor, and made a new canal from thence to Delhi, which is about 60 miles.

The other principal canal was from the river Sutlege to the city of Hipai Ferozeh, thus mentioned in Ferushta, translated by Dowe. "He (Feroze) drew a canal from the Cagger, passing the walls of Sirsutti, and joined it to the river Kera, upon which he built a city, named after himself Ferozabad; this city he watered with another canal from the Jumnah; those public works were of prodigious advantage to the adjacent countries, by supplying water for their canals, and a commodious water-carriage from place to place.

Besides these principal canals, several branches were cut in different places; and, on the banks of both, towns were placed; as Juneed, Dhatarest, Homsi, and Ioglickpoor. Feroze levied a tenth of the produce of the lands fertilized, which, with the revenue of the land lately cultivated, he applied to charitable purposes; and it is said that the lands of Ferozeh, which had formerly produced only a scanty harvest, now gave two that were abundant.

Besides these canals connected with Ferozabad, there are similar works adjacent to Lahore, on the S. E. bank of the river Hydroates of Alexander. This noble river has its source in the mountains near Nagerkote; it enters the plains near Shapoor, or Rajapan; and it is from this place the canal of Shah Nehr has been carried a distance of about 73 miles, to supply the city of Lahore with water. From the same place three other canals were taken for watering the country to the S. E. of Lahore, in dry seasons, when all the Indian rivers are from 20 to 30 feet below the level of their banks.

The meritorious exertions of this excellent prince, are an evidence of what may be accomplished in those fine countries, since, besides intersecting the adjacent plains, the branches of the Indus might be connected with those of the Ganges, and an inland navigation opened between the confines of Persia in the west, and those of China on the east.

The Ganges and Burrampooter are, in many respects, similar; the sources of both are in the mountains of Thibet; they both, for some time, proceed through rugged countries, in nearly opposite directions, until they are about 1200 miles apart; they afterwards mutually approach, and finally unite, previous to discharging their mighty body of water into the Bay of Bengal. They have also a resemblance in their inundations, their colour, smoothness, islands, and shores.

The Ganges, after winding amongst rugged mountains for about 800 miles, rushes through a rocky chasm at Hurdwaar or Hardoar, in Lat. 30°. It afterwards traverses the plains of Hindostan by a course of about 1350 miles, in which it receives eleven rivers, several equal to the Rhine, few less than the Thames. From Hurdwaar to Jumnah, about 750 miles, its breadth varies from a mile to a mile and a quarter, from thence downwards the channel becomes wider: above the junction of the

Jumnah, it is in some places fordable, but the navigation is never interrupted. Below this junction it acquires more depth than breadth. At 500 miles from the sea, the channel, in the lowest state of the river, is 30 feet deep, and continues so to the sea, except where the velocity is checked by sand banks, thrown up by southerly winds.

The head of the Delta is at 200 miles from the sea in a direct line. The two western branches (the Cossombuzar and Jellinghey rivers) unite and form the Hoogley river, which is the port of Calcutta, and the only branch of the Ganges usually navigated by large vessels. The Cossombuzar river is almost dry from October to May. And the Jellinghey river, although it has a stream the whole year, is sometimes unfit for navigation for two or three of the driest months. The Chomdah river, which separates at Maddapoor, and terminates at Houngatta, is the only subordinate branch at all times navigable. The part of the Delta next the sea is a labyrinth of creeks; salt, except those next the principal branch. The channels which intersect it afford a navigation throughout the Delta. The tract, named the Sunderbunds, (or Woods) is equal to Wales in extent.

From Hurdwaar to the sea, has been considered as one uniform plane; by order of Mr. Hastings, a section for 60 miles, parallel with one of the branches, was found to have a declivity of nine inches in a mile, reckoning in a straight line, but allowing for the winding less than four inches per mile. The mean motion, in dry seasons, is less than three miles per hour; after the inundation, when the water is draining off, it is from five to six miles; there have been instances of from seven to eight miles. During eleven years, the head of the Jellinghey river has moved three-fourths of a mile farther down, and by surveys taken nine years apart, it appeared that the breadth of a mile and a half had been taken away. A mile in ten or twelve years, is reckoned the usual encroachments, at the places where the current strikes with the greatest force. There are many instances of total changes, not only in the branches, but over the whole river. The Cosa river, equal to the Rhine, once passed Purneah, and fell into the Ganges opposite Rajemall; its junction is near 45 miles higher up. Gour, the ancient capital of Bengal, stood on the bank of the Ganges; its ruins are near four or five miles from it. Along the coast of the Delta, not less than eight openings appear to have been alternately the mouths of the rivers. The banks of sand and meadows now extend about 20 miles into the sea beyond the islands in the mouth of the Ganges, and in some places rise within a few feet of the surface of the water. There is no substance so coarse as gravel in the Delta within 400 miles of the sea.

The Ganges owes its increase as much to the rain that falls in the mountains contiguous to its sources, as to that which falls on the plains of Hindostan; for it rises 15½ feet out of the 32, its total rise, by the latter end of June; and the rains do not begin in the flat countries until about that time; in the mountains it begins in April, and by the latter end of that month the river begins to rise, at first only one inch per day for the first fortnight; it then gradually augments to two or three inches before any rain has fallen in the plains. When the rain becomes general, the mean increase is five inches per day. By the latter end of July, all the lower parts of Bengal, contiguous to the Ganges and Burrampooter, are overflowed, and form an inundation more than 100 miles in length, nothing appearing but villages and trees. The ground adjacent to the river is, for some distance, higher than that which is more remote, and separates the water of the inundation from that of the river, until the latter overflows; this higher ground is in some seasons covered one foot. The depth of the inundation beyond the banks varies; in some parts it is 12 feet; but, at the height of the inundation, the course of the river is evident from its greater motion and muddy colour. The motion of the inundation does not exceed half a mile per hour.

It is calculated that dykes of above 1000 miles in length have been constructed to protect one particular district. One branch of the Ganges, navigable only during rainy seasons, is conducted 70 miles between two of these dykes; and, when full, passengers look down upon the country. When the river is full, the tide cannot counteract the downward current. It is not uncommon for a strong wind to swell the waters two feet above the ordinary level, and has occasioned the loss of whole crops of rice. The inundations are navigable in all directions, in straight lines, and smooth water.

The following is a Table of the increase of the Ganges and its branches.

	At Jellinghey.		At Dacca.	
	Feet.	In.	Feet.	In.
In May it rose	6	6	2	4
In June	9	6	4	6
In July	12	6	5	6
First half of Aug.	4	6	1	11
	32	0	14	3

These observations were made in a season, when the water rose higher than usual, so that 31 feet may be taken as the mean increase. Some days before the middle of August, the inundation is at a stand, and begins to run off, although great quantities of rain fall in the low countries during August and September. The daily decrease, in the latter end of August and all September, is from three to four inches. From this to the end of November, it lessens gradually to one inch and a half; from this to the latter end of April, half an inch on an average. The decrease of the inundations does not always keep pace with that of the river; but after the rain has nearly ceased in the beginning of October, the remainder passes off quickly, chiefly by evaporation, leaving the land richly manured.

It is a fact, confirmed by repeated experiments and observations, that from the place where the tide commences at the sea, the height of the periodical increase diminishes gradually, until it totally disappears at the point of confluence.

The quantity of water discharged by the Ganges in one second of time, during the dry season, is 80,000 cubic feet; but the river taken full, having thrice the volume of water in it, and its motion being also accelerated as five to three, the quantity discharged is then 405,000 cubic feet. If the medium of the whole year be taken, it will be nearly 180,000 cubic feet in a second.

The Burrampooter, for 60 miles from its junction with the Ganges, is from four to five miles in breadth. This great breadth, it is conjectured, may have been formed when the Ganges joined, where the Ismutty now does. In the remaining 340 miles of its course in the province of Bengal, it in many respects resembles the Ganges; its whole length is reckoned more than that river, and their sources are at no great distance. When they unite below Luckipoor, they produce a stream not equalled in the old hemisphere, and in rainy seasons render the surface of the sea fresh for many leagues.

In the channels between the islands at their mouth, the bore rises from 5 to 12 feet; after the tide is fairly past the islands, no vestige of the bore is perceived. In the Hoogley river, the bore commences at Hoogley point; it is visible above Hoogley Tower, about 26 miles below Calcutta; and the motion is so rapid, that it scarcely takes four hours between them. At Calcutta it sometimes occasions an instantaneous rise of five feet. The boats generally make for the middle of the stream.

From October till the middle of March, when the north winds begin to blow, the rivers are in a tranquil state. The winds are more violent in the eastern than the western parts of Bengal; they happen most frequently towards the close of the day; they are preceded by irregular coloured clouds in the latter end of May and beginning of June. From the beginning of November to the latter end of May, the usual rate of going with the stream is 40 miles per day in 12 hours; and during the rest of the year from 50 to 70 miles. The current is strongest in part of August and September, while the inundation is running off. The motion acquired by using oars in a large budgerow hardly exceeds eight miles per day. A budgerow is a travelling boat, with a cabin 14 feet wide, and proportionally long, and draws from four to five feet water. In towing against the stream, the side is generally preferred where the banks are steep, on account of the greater depth of the water; and from 17 to 20 miles per day is the greatest distance passed over; and, to accomplish this, the boat must be towed at the rate of 4½ miles per hour for 12 hours. During the inundations greater progress can be made, because angles can be cut off, and sails used.

Calcutta is situated upon the Hoogley river, 100 miles from the sea; it is navigable up to the town by the largest ships which visit India. The largest boats upon the Ganges vary from 300 to 600 maims, and their hire is from 20 to 30, or even to 60 rupees per month. A budgerow for gentlemen and their families, having from 8 to 24 oars, are hired, for the smallest 60 rupees, for the largest 230, per month. Upon the whole, by these two great rivers, every part of the province of Bengal, with a few exceptions, has, even during the dry seasons, a navigable stream within 25 miles, and generally much less. All the salt, and much of the food, for ten millions of people, also exports and imports to the value of two millions sterling per annum, besides interchanging manufactures, fisheries, and travelling, employ upwards of 30,000 boatmen.

3. The principal rivers in the Peninsula, south of the Indus and Ganges, along the east coast, are, the Godavery and Bain, the Kitsnah, Pinnac, and Caveri; their lengths vary from 300 to 700 miles; the latter is the length of the Godavery, which forms, near its mouth, a sort of Delta, with sundry branches, which are the most accessible inlets between Bengal and Cape Comorin. There are valuable teak forests upon its banks within the mountains.

To the south of the Kistnah to Cape Comorin (including Madras) a distance of 600 miles, there is no port for shipping, the coast forming nearly a straight line. The dangerous surf on the coast also requires boats of a singular construction; they are formed without ribs or keel, having their planking sewed together; and in consequence of this flexibility they receive without injury the breaking of the surf.

From Cape Comorin, along the western coast of the Peninsula, the first river is the Paniang, which passes through a singular opening in the Ghaut range of mountains. North of this river the Ghauts approach near the shore, so that there is no river until we reach Surat, near the root of the Peninsula, where the Taptu river of 400 miles empties itself. Further north, in the Gulf of Cambay, is found the mouth of the great river Nerbudda, whose length is about 700 miles. As the upper parts approach within a small distance of some of the branches of the Jumnah, it seems to offer an opportunity of forming a connection with the Ganges.

4. Between Hindostan and China are three great rivers, viz. the Aracan or Kempoo river, the Ava or Irbetty or Irwady-river, and the Japanese, or Lantsan-ho. Their sources are in the Thibet mountains, at no great distance from each other; the first, after traversing the country of Aracan, falls into the Gulf of Bengal; the second, after traversing the Birman Empire, forms an extensive Delta, and sundry branches and mouths at the south-east extremity of the Bay of Bengal; and the third, crossing the kingdoms of Laos and Cambodia, falls by several mouths into the Sea of China. The length of the Ava is reckoned 1200 miles, and has several thousand boats navigating upon it. The other two are not much inferior.

We have been thus particular in respect to Hindostan and its vicinity, as it now forms an important portion of the British Empire, and is otherwise a very interesting subject.

Persia, and Western Asia.

Persia being chiefly mountainous, and the inhabitants, from their situation and habits, being averse to foreign connections, and little addicted to the pursuits of industry, have no inland navigation, excepting some junctions of the Euphrates and the Tigris near the top of their joint Delta.

These two rivers have their sources in the Taurus ridges, at the distance of about 250 miles from each other. They inclose the country of Mesopotamia, or modern province of Algesiras, and, after watering the plains of Babylon, unite, and pass by one channel into the Persian Gulf. The natural slope of the country is from the Euphrates to the Tigris; the plain of Babylon being subject to be overflowed, these rivers were early confined by dikes, and regulated by drains or canals, and lakes. Many of them were attributed to Nebuchadnezzar. The most considerable canal passed to the Tigris near Ctesiphone. Pliny calls this Armaldhar; in the language of the country it is Nahar Malcha. Besides connecting the river floods, some canals were made for irrigating land.

Alexander caused some of the canals to be cleansed, and made some new ones, one nearly 30 stadia in length, where he built a city, gave it his own name, and established a colony of Greeks. Arian says, that this prince embarked upon the river Eulocus, to proceed to the sea by the mouth of the Tigris, and that a part of his fleet passed into the Tigris by a canal about 30 miles from its mouth. M. Oberlin (p. 33,) says that there was a canal of 25 miles in length, by which the Euphrates was turned southward into the Tigris towards Seleucia, also one towards Apamie, besides that formerly mentioned towards Ctesiphone. Tillemont, after Dion, says, that Trajan drew a canal from the Euphrates to the Tigris; perhaps he only opened and cleaned the old one. Severus completed this, and conducted vessels from the Euphrates into the Tigris.

Alexander is said to have caused an isthmus of seven miles to be cut through, which joins the peninsula of Mount *Mimas*. This peninsula projected 250 miles before the rest of Asia Minor towards Clasomene, to the side of Ionia. (Pliny, v. 31. Pausan. l. ii. s. Corinth.)

With regard to the western and interior districts of Asia, it being well accommodated by the Euxine and Caspian Seas and their rivers, little artificial aid has been required or attempted. The Caspian is about 700 miles from north to south, and from 100 to 200 from east to west; its water is salt, bitter, and impure; its depth, in the middle, is said to be 500 fathoms, but the shores are everywhere flat. It has scarcely any safe port; the best is Daku; Derbent is rocky, and Enfili is incommodious. The north, north-east, and south winds are tempestuous. A small rise and fall of water is observable. Fisheries constitute the principal business of this sea. It receives the great Volga, the Juimb, and Uralia from the north-west. From the west are the Kuma, Terek, and Kizen; and the Tegin from the east. Also formerly, the Gihon or Oxus, which now flows into the Lake Aral.

In 1815, Messrs. Maurice Engilhart and Francis Parrat published, at Berlin, the results of barometrical measurements between the Euxine and the Caspian, by which it appears that the Caspian is 105 metres below the level of the Black Sea; the distance between them, over which the measurements were taken, in a straight line, is 813 versts. About 100 miles east of the Caspian is the lake Aral, 200 miles in length, and 70 in breadth; it receives the Oxus, or Gihon, the Sin and Sihon. There are also various large lakes in Asia, besides rivers of very considerable magnitude; but, as they are little used for navigation, we avoid noticing them.

Greece, and Turkey in Europe.

Ancient Greece, being composed of small states occupying mountainous districts, either intersected by arms of the sea, or islands and sea-coasts, the attention of the inhabitants was never turned to inland navigation. Although often mentioned as a project, it does not appear that the Isthmus of Corinth was ever intersected by a canal, so as to be used for navigation; and the tunnels from the lake Copais, in Bœotia, through Mount Ptous, are distinctly described as drains, having wells at certain distances, to facilitate the cleansing them out.

The modern state of that country has been degraded by the Turks, as well as the districts held by them in Europe. It is therefore in vain to look for artificial improvements, where natural advantages have been so totally neglected. The Danube, which, for more than 400 miles, with its extensive branches, is Turkish, is alone sufficient to accommodate a powerful empire. There is, besides, the Maritz, or ancient Hebrus, 250 miles in length, which falls into the Ægean Sea, and the Vandori, or ancient Auxius, 200 miles, which falls into the Gulf of Salonica, and many other fine streams, which, under good management, would connect more extensive countries than the opposite Italian shores, which have been so justly celebrated.

Ancient Italy.

Although the pursuits of the ancient inhabitants of Italy were generally connected with war, they were occasionally led to operations connected, either directly or indirectly, with inland navigation. The canal of the Pontine Marshes proceeded from the Forum Appii, across the Pontine Marshes, to near Terracina; and was intended both for the purposes of drainage and navigation. The consul was charged with works to render his province fertile and healthy. (Pliny, l. iv. c. 4.) This work was accomplished 162 B. C. Having fallen to decay, Cæsar proposed to renew it. Plutarch says, that Augustus drew a canal parallel with the Appian way. Trajan, by a labour of 10 years, restored the drains of the Pontine Marshes, (Dion. l. xviii. p. 777) as did Theodoric the Goth.

But in ancient, as well as modern times, the neighbourhood of the Po has been the great scene of Italian inland navigation; its source is in Mount Vesula, or Viso, on the confines of France, and its length, of course, is about 300 miles. Pliny says, that the Po is greatly augmented by the melting of snows, and that, after receiving 30 rivers, it falls into the Adriatic. It appears from Polybius, that it formerly passed to the sea by two mouths, and that vessels ascended by the branch named Olana, (Polyb. l. ii.) Of the other branches, some were formed by nature, and some by art. Pliny (l. iii. c. 16.) mentions the canal which conducted to Ravenna; its mouth was named Vatrinus, and had the capacity of a port. It was by it that the emperor Claudius entered the city of Adrian, after his expedition to Britain.

The Etruscans dug the canals from the branch named Sagis, from which they made side cuts into the adjacent morasses; but, besides those before mentioned, they drew from the Po, above where it separates, a great canal, named Fossa Phillistina, which is also divided into two canals, the most northern of which was named Fossiones Phillistinæ, and the southern Fossa Carbonania. According to Pliny, the Athesis and Togisonus, after uniting, formed the port of Brundulus; the other streams, named Medoacus Major and Minor, formed, with the canal Fossa Clodias, the port of Edron. The last branch derived from the Po, was the Fossiones Phillistinæ, joined to the stream Tartaris, or Athesis, and was named Tartaro Phillistinæ; there were other inferior connecting canals. But the most celebrated of all the canals, was that named Fossi Augusti. One branch of the Po, named Fossa Ascon, washed the walls of Ravenna on the north side. The emperor Augustus drew a canal from the same river, which passed to the sea by the south, and one branch traversed the city. (See Cluv. Ital. Antiq. l. i. p. 398.)

It was not surprising that the Po, near the sea, should be named the seven seas; for all the country (the plains of Venice) was then a morass, frequently covered with the sea, so that canals were dug, partly for agriculture, and partly for navigation. This aquatic plain extended, by the inundations of the Po, caused by the Trebia, and other rivers, far into Cisalpine Gaul. Camillus Scaurus, 115 B. C. drew navigable canals from Placentia to Parma. (Livy, lib. xxxviii.)

In the correspondence between Trajan and Pliny, mention is made of sluices, but there is no reason to think that locks with double doors are meant, because no such were known to have been executed by the Romans. If they had once been adopted, their utility would have ensured them from falling into disuse.

Modern Italy.

Modern Italy, having recovered from the stupefaction which succeeded the destruction of the Roman empire, brought into action the seeds they had preserved of eastern knowledge, and as soon as property became protected by regular government, and commerce had introduced wealth, the first efforts of industry and art were directed to the drainage of marshy lands, and the construction of banks to regulate rivers, whose beds had been raised by gravel and mud brought down from the mountains. The next step was artificial canals for irrigation and inland navigation, and finally, sluices with double doors were completed. This most important step in the progress of inland navigation, was accomplished in the year 1481, by two engineers of the town of Viterbe. (Zendrini, c. 12.) These improved sluices were soon afterwards duly appreciated by that enlightened and scientific artist, Leonardi de Vinci, in the canal of junction executed under his direction at Milan; and inland navigation became so important, that the Italian governments enacted many laws respecting it, and the most learned men of the country wrote elaborate treatises respecting the management of water.

On entering the Milanese, many canals are found carrying water for irrigation, and two that are navigable, and these form a communication between the Tesino and the Adda, and unite at Milan. Near to Olleggio, a canal has been taken from the Tesino, which passes Buffolaro, Biagrasso, and Arsago, to Milan; its length is 15 miles; it is named Naviglia Grand. From Abiato, a branch of about 11 miles proceeds southwards; its breadth at the bottom is 46 French feet, at top water 130 feet. It was in 1257 extended to Milan, and was enlarged in 1269. The Herugando branches from the last mentioned. It was made in 1457, and has now 11 sluices.

From the right bank of the river Adda, near Concessa, (the ancient Trizzo,) the canal named Martesena, is taken off. It is 24 miles in length, and 33 feet in breadth; it is in some places sustained by thick walls and earthen mounds, 110 feet above the level of the river. Some French authors attribute this great work to Louis XII. and Francis I. Italian authors ascribe it to Francis Forza I.—and state, that, on the 1st July, 1457, he named commissioners for the work. It is certain that Louis Forza, the son of Francis, rendered it navigable round Milan, and formed depots for merchandise. It was at this time, 1497, that the five sluices were introduced.

The great canal of Tesino, and the branch which goes from the side of Pavia, unite at Milan. The Muzza is another canal drawn from the Adda; it commences near Cassano, and re-enters near Castiglione, which is 40 miles distant. Upon this length there are various branches for irrigation, in the districts of Milan and Lodi. The Adda, above the intake of the Montesano, is not navigable to the lake Como; it was attempted in 1519, but did not succeed. The fall is 84 feet in five miles. The channel is rocky and irregular.

The canals of Piedmont are less ancient and less considerable than those of the Milanese; but there are five of some consequence. 1. The Naviglio d'Inea, of 38 miles, which unites the Dora Baltea with the Sessia. A branch from this, of 15 miles, joins the Gardena river. 2. A canal of 27 miles, from Dora Baltea, a little above the falls of the Po, which, after passing Trino, falls into the Po, four miles below Casal—these two canals are nearly parallel to the Po, and substituted for it. 3. A canal of three miles from the mouth of the canal of Trino. 4. The Naviglio Novo, which proceeds from Sturo, near Coni, to the Po, near Carmagnol, 10 miles above Turin. 5. Above Novare, a canal of three miles unites the Cogno with the Tordopio river. The canal of Mora Noviglio begins at the end of the canal of Novare.

Along the Po, below the Milanese, the canal named Albinea, 20 miles, commences in the Pogna, near Nibiola, and falls into the Po near Albignolo, 10 miles above Pavia. In the Cremona, the canal named Naviglio della Communila, between the Lerico and the Oglio, falls into the Po near Cremona, four miles below the mouth of the Adda. A canal of three miles goes from that of Cremona, and falls into the Oglio. Another canal of eight miles begins in the Po, near Cassal Maggiore, and falls into a river which joins the Oglio below Gustalla.

In the duchy of Mantua, the canal called Fossa di Puzzola, 15 miles long, goes from the Mincio, near Geito, and falls into the Tartaro. The canal of St. George, six miles long, goes from the lake of Mantua to the canal of Puzzola. The canal of Martenaro, eight miles, goes also from the same lake to the Po, at Borgo Fute. The canal Fossa Maestra, five miles, comes from Ozoma to the canal Montanara. The Fossero, which comes from the Mincio, is seven miles.

In the duchy of Modena is a canal 16 miles long, from Secchia to Panaro, by Modena. It has several branches, one of which is five miles long.

In the estates of the Pope, Fossa Rangone runs parallel to the Panaro, and joins two others, one of which goes by Conti to Po Mort, or Po de Jerana. The canal di Giovanni Niginales, from the side of Mansolino, is 22 miles long; below Conti it is named Condotto di Conti. From Bologna to Ferrara is a canal of 24 miles, named Canal di Naviglio; it terminates in the great marshes. The Canal di Medicina falls into the Po at Primaro. Still on the side of Ferrara is the Canal di Bianco, the Naviglio Ferranese, which goes from the Great Po to Po Mort; the Canal Val d'Albama, a canal of six miles, goes from the Po into the Gulf of Venice. The other canals being so numerous, and without any remarkable features, it is needless to notice them. Many are for irrigation only.

From Ferrara to Venice the passage is made partly by the Po, and partly by canals. At Ferrara, we embark upon the canal Ponfilio, and, after an hour and a half, arrive at Pont di Lago Oscuro: then we enter the Great Po, and continue upon it 40 miles from Ferrara, and 50 from Venice; then we enter a canal named La Cavanilla, and, after passing along it four miles, we arrive at the village Laurio. After proceeding three miles to Cavanell del Adige, making two miles upon the Adige, seven miles farther, we find the Sluices di Brondo, 28 miles from Venice, by which we enter the Venetian Lagunes, that is to say, a sort of lake, whereof the low tranquil waters are not agitated by the sea.

Formerly, the only navigation at Padua was the Bacchiglione; it passes near Vincenza, and there receives the Rherone, after which it is navigable by barks of considerable size. From Padua it passes, by a winding course of about 50 miles, to the Levant at Bundolo; between Padua and Vincenza there are nine sluices. The first is a perfect lock, with a fall of eight feet; the others are only Pertuis, named in the country Bova, which will be described afterwards. At Padua, the principal arm of the Bacchiglione separates into several branches. Two canals encompass the city, one for mills, the other for navigation. After leaving the city they reunite.

In 1201, a canal was taken off the river, 11 miles above the city of Bassanallo. At eight miles it meets an ancient river named Vego Seno. This canal passes two aqueducts, the first near Mensellisse; it affords a passage to vessels carrying stones for the buildings in Venice. The second, named De Pegozza, admits water from the country of Padua and Vincenza. The united waters proceed three miles to Dolo, and afterwards, under the name of Brentone, to the Sea or Basin of Brondolo. The water of the Piovego was long kept up by the Bovas only; but, in 1481, the Venetians caused to be constructed a sluice with double gates, which is considered the first example of a perfect lock. The credit, as has already been mentioned, is due to two brothers of the town of Viterbe; the fall was five feet. A mile above Brenta, a canal of seven miles was made in the 12th century. The great sluice of Padua, named Porto Contarine, has 6⅓ feet fall, and was constructed in 1505.

The Brenta begins to be navigable 15 miles above Padua. Five miles above that city it separates into two branches, the left by the name of Brenta Vecchia, goes to the village of Stra below Padua; the right branch, named Brentella, unites with the Bacchiglione, some miles above Padua. The Venetians have repeatedly changed the course and branches of the Brenta. The Brenta communicates with the Adige by a canal of six miles from the basin of Brondolo, at the mouth of the Brenta, across the marshes. A branch entirely artificial, 20 miles in length, passes from Padua to Venice; it has 50 feet fall, divided into four locks. Notwithstanding all these numerous works on the Brenta, they were found insufficient, and in 1777, P. Ximenes, P. Frisi, and M. Straties, were appointed by the senate to consider a plan by M. le Coloneli Lorgna respecting the disorders of the Brenta.

The actual bed of the Po, which carries the waters of this great river to the sea, which is named Po de Venice, was formed in 1167 by an opening in the dykes at Tevaralo. Besides the Cavanello di Adige, there is another sluice at Brondolo, which has 12 feet fall.

The lagunes are skirted by a canal 36 miles in length, named Novella Brenta. The Sill river commences in the plain, some miles above Treviso, and is navigable from that city to the sea, a distance of 40 miles by the river. It still communicates with the lagunes by a canal named Siomello, which has two sluices; and the gates, constructed in 1686, have eight feet fall.

At Rome it has often been proposed to make the Tiber navigable from Perugia to the mouth of the Nera, from whence to the sea it is now navigable. But Manfredi, in a report dated 1732, says, that the Tiber, having a fall of eight or nine Roman palms per mile, is too rapid for navigating upwards: he therefore proposes sluices; but the project was abandoned.

The canal of Leghorn is the most considerable in Tuscany. It is 15 miles long, 45 feet broad, and four or five feet deep. It derives its waters from the Arno, and falls towards Leghorn; but the slope is so gentle that barks easily pass upwards, hauled by men. The river Arno continues navigable through Florence to Arraro, where the Canal di Chiano prolongs the navigation to Monto Pulciano.

Holland and the Low Countries.

The northern part of Germany is one immense plain, descending gently towards the sea, there being no considerable mountain within 150 miles of it; and from Blankness, at the Dover Straits, to the coast of Denmark, the shore exhibits chiefly a range of low sand hills, occasionally broken to admit the exit of the landwaters from the great plain.

Behind this range of sand hills lies a shallow basin, about a mile in width, occupied by a bog or morass, the surface of which is but little above the level of the sea, and the bottom from ten to twenty feet below it. The breadth of this space frequently varies, the great inlets of the Zuyder-Zee still exist, unfilled with peat; and, according to tradition, was a lake only, until the Cimbrian deluge, breaking the northern boundary of the morass, had admitted the sea into Friesland. But the continuous parts of the morass are chiefly adjacent to great rivers. Now, it is the nature of all rivers liable to inundation, to deposit great part of the sullage on their immediate banks, and raise them higher than the morass behind; and this valuable land may have suggested the idea of completing and extending the works, by embanking the rivers, and securing the meadows by dykes. The embankments of the Rhine, at least of the great island Betuwe, is more ancient than the invasion of Cæsar. Although the state of the country must have rendered inland navigation unavoidable, yet it does not appear that any artificial canal was constructed previous to the time of the Romans, when Drusus formed the derivation from the Rhine to the Yssel at Dæsburg, 12 B. C. (Tacitus, *Ann.* ii.) He is also said to have embanked the Rhine. Corbulus, one of the ablest of the Roman Generals, employed his soldiers in excavating the Fossa Corbulonis, to unite the Rhine and the Meuse. It was twenty-three miles in length; and may have been the origin of the present canal of Delft, extending from Leyden to Maesland sluice. Claudius Civilis formed the river now called the Leck. This river passes with a crooked course, and on a high level, to join the Meuse at Flaardirgen. It has been embanked in later times.

In the middle of the fifth century, the channel of the Merwe, or Merwede, was formed by Meroveus, king of the Franks, from the Meuse to the Waal, at Dordtrecht, to join the Leck at Krimpen; the mouth of which is now considered as the mouth of the Meuse.

The Emperor Otho, in the tenth century, cut a canal from Ghent to the sea; and besides the beforementioned, many cuts and channels have been effected by inundations. Of this kind are the Risbosch, (or Bulrush Forest,) to the westward of the city of Dordtrecht, which occurred in 1421, by an irruption of the Meuse.

Besides the natural lakes, the interior navigations are continually extending, by cutting turf for fuel, which, reaching to the depth of from twelve to twenty feet below low water, leaves a new lake. These sheets of water, called Plassen, or Plashes, by the Dutch, are all one level within certain districts, and uniting with the canals, are navigated by the sail or perch; but as many of these plashes, when united, form great lakes, which have waves, and which corrode the adjacent lands, it is the policy of the Dutch to have them drained and cultivated. For this purpose they are surrounded by dykes, to keep out the foreign waters; on the outside of which a ringsloot, or surrounding drain, is made of dimensions sufficient to be a navigable canal. The water is then raised from the interior polder by means of windmill, to the ringsloot, along which it passes into the sea. The bottom of the polder, or drained land, has also drains, which in some cases are navigable, but they never communicate with the exterior canal, or ringsloot. Nearly all the lakes of North Holland were reclaimed in this way about 150 years ago: Much has also been done in South Holland. To the extent of about 20,000 acres, has been lately drained under the direction of the intelligent M. Brunings of Leyden. Great part of that province is however still under water, especially adjacent to Rotterdam.

The navigations of Holland are intimately connected with drainage, and could only be so multiplied in a country, which, being nearly flat, made it necessary to gain elevation over the usual level of the waters, by sacrificing a portion of the surface; but as the nation became commercial, the convenience of water carriage caused an amazing increase in the number of canals. The older parts of the cities in Holland were usually constructed with the streets along the dykes. The newer parts have a canal in the middle of every street, with a spacious quay on each side, shaded with trees. There is scarcely a town of any note but what is provided with one or more canals. This has been chiefly effected by connecting and embanking the ancient brooks and rivers, and retaining the water at a sufficient height by sluices and dams. The artificial canals are therefore not so numerous as might be imagined. The construction of a *dam* necessarily implies the formation of a port, at which the sea, or tidal navigation, might be exchanged for that on still water. Hence the frequent occurrence of this word as the termination of the ports of Holland. It was not, however, until the navigation of Holland had attained a considerable perfection, that the invention of the lock permitted the transfer of the sea vessel into the interior.

North Holland.

The river Saam appears the parent of the interior navigation of North Holland. It formed the outlet for the waters of the lakes Beemster, Schermeer, &c. now drained and cultivated. It gave a navigation to Alkmaar; and as this city may be considered the central point of North Holland, we shall begin our description of the canals from thence.

1. *Canal to Zaand.*—Its course is towards the north for 7½ miles, to the ancient sea dyke of West Friesland, where a lock lowers it into the cultivated marsh of Zype; and from this point a branch 2½ miles passes to Potten on the North Sea. On looking down into the Zype, the canal proceeds nine miles along the main drain of that district, to the dyke separating it from the Wieringer Waard embanked marsh; and a cross drain of three miles completes the navigation to Zaand, at the northern extremity of the Zype.

2. *Canal of Egmont.*—Five miles to the west of Alkmaar lies the coast town of Egmont-op-Zee, and a cluster of villages line the inner side of the downs. The intermediate space between them and Alkmaar, formerly a lake, now drained, and intersected by canals, viz. one towards Bergen on the north side, and which, surrounding the Berger Mere, (the first lake drained in North Holland.) unites with it; 2d, A canal to Schuglenburg, with two branches; 3d, A canal of five miles to Egmont-op-de-Hoog, with two branches uniting at Egmont Abdy. The total extent of these canals is about 20 miles, intersecting a country of about five miles by three. They are in fact ringslooten, or surrounding drains, and their banks divide the general lake into three large and several smaller compartments, or polders, from which the water is raised by mills to the general level of the canals.

3. *Canals to Colhorn, Medenblick, &c.*—On the eastern side of Alkmaar, and at a mile distant, is the drained lake Schermeer. On the north of this is the drainage called the Huygen Waard. The ringsloot surrounding it for 21 miles, is navigable, and has many branches, making in all about 19 miles, pervading a country about 6 miles by 3½ miles. They connect with the sea at Colhorn by a tide lock.

4. *The Canal to Hoorn* was made in the beginning of the 17th century. It passes by the ringsloot, between the Huygen Waard and Schermeer to Ursem, and from thence by a canal of nine miles to Hoorn, on the Zuyder-Zee.

5. *Canal to Parmeronde and Edam.* The Schermeer Lake has a navigable ringsloot of 21 miles, of which four miles of the north are common to it and the Huygen Waard. This also connects with the ringsloot of Schermeer seven miles, and that with the ringsloot of Beemster 24 miles in circumference, thereby completing the communication with Alkmaar, Hoorn, &c. &c.

6. *From Cnollendam*, at the south extremity of Schermeer, the river Saan is navigable for large barks to the sea sluice at Saardam.

7. *Canal of Naauwarna* opens another communication from Cnollendam to the Ye. Its length is seven miles; and a stone sluice at Naauwarna joins it to the Ye. This is the direct line of communication from Haarlem, &c. into North Holland.

8. *Parmeronde* also communicates by the side of Beemster with Alkmaar and Hoorn, likewise towards the south-west, with the river Saan at Calf; and it has, besides, a communication towards Amsterdam by a canal of eight miles.

9. The canal to *Mannikendam*, in its passage, communicates with various lakes and drains in the eastern part of Waterland, affording every where a ready means of conveyance to Amsterdam.

Besides these leading routes, there are many others of smaller dimensions, by which inland navigation is extended not only to towns, but even villages, and the interior of farms. Where locks are not constructed, the connection between the higher and lower levels is by means of inclined planes, and rollers worked by capstans.

With the exception of drainage, all the canals are upon one level, which is a little above the ordinary low water of the Ye, or Zuyder-Zee; therefore locks are only required to pass into or from the sea at high water, or into one of the main drains of the Polders.

Canals of South Holland.

The canals of this province also owe their origin to drainage. From Naarden, on the Zuyder-Zee, a ridge of dry ground and heath extends to Rhenen on the Rhine. The country to the westward is flat, and occupied chiefly with a morass to the line of downs, which divides it from the North Sea. The drainage, until the present century, was divided into a variety of portions, under independent jurisdictions. Of these—

1. Rhineland comprehended the Haarlem Mere, and lower basin of the ancient Rhine, from the sea to the Mye, draining to the River Ye.

2. Amstelland, to the east of Rhineland, comprehending the basin of the Amstel-river, and draining to the Ye at Amsterdam.

3. Goyland, east of Amstelland, comprehending the Vecht, from New Sluis to Mugden.

4. Delftland, south of Amstelland, extending from the mouth of the Meuse to Schiedam.

5. Schieland, the portion of the Meuse above Delftland, and extending to Gouda along the Leck.

6. The Watership of Woorden, along the Rhine, between Rhemon and Utrecht. The southern insulated portions of the province were also under separate jurisdictions. The states of Utrecht regulated the upper portion of the flats, between Goyland and the Leck.

Each district has, by means of locks, its waters preserved at the same level; and is pervaded by canals and numerous lakes, all connected together, and affording the utmost facility to navigation. But as we cannot be expected to enter into minute details, we shall confine our observations to the general routes.

Canals of the Jurisdiction of Rhineland.

This jurisdiction seems to have been established previous to 1253, when a charter was granted from William, king of the Romans, for the canal of Sparendam. The interior navigation of Rhineland begins at Sparendam on the Ye, near Haarlem, for vessels not drawing more than six feet. They are admitted by sea locks into the river Sparen and town of Haarlem; from thence they may pass into the Haarlem Meer, and crossing it, proceed to Leyden and the old Rhine, by means of various navigable channels.

The old Rhine ran originally into the sea at Catwyk, near Leyden; but the river had lost the power of preserving its channels, and the sand blew across it in 841 A. D. and rose into downs. Since that period, the small quantity of water which passes towards Leyden finds its way by the Haarlem Meer, or by Amsterdam, into the Ye. It was only after the union of the several waterships, under the late Batavian republic, that this great work was seriously taken up.

The Rhine communicates, for ship navigation, with the Issel and Meuse by Gouda. A ship-lock at the Gouda Sluis passes the vessel across the dike of the Rhine, into a spacious canal connected with the Crome Goura river. This was made in 1281 as a slaker to the Rhine. It is nine miles in length, and has an excellent tide-lock at Gouda on the Yssel, 153 feet long, and 25 wide in the chamber. The vessels chiefly employed are called Cologne ships, upon five or six feet water, and are often 1000 tons burden.

Besides the ship navigation, there are many track canals through Rhineland:

1. The Treck Vaart from Haarlem to Amsterdam, five miles upon one level. Passengers then walk across the sluice bridge, and again embark on the second part of the canal for 5½ miles farther, to the Haarlem port of Amsterdam.

2. The canal from Haarlem to Leyden, 18 miles, made in 1657, between the Downs and Haarlem Mere.

3. From Leyden the Rhine is navigable towards Woerden and Utrecht, and is regulated by locks. It has many navigable branches: Of these, the Hoogweense Vaart, and two others, communicate with the great plashes, or cut away bogs; and from thence small barks pass by the river Rotte to Rotterdam.

From Leyden to Delft the canal is by many considered as being the Fossa Corbulonis, and probably a part of the ancient excavation has been adopted. It continues on the general level of Rhineland from Leyden, seven miles to Leidsendam. A large basin at this village serves as a lock chamber for connecting the navigation of two districts. The difference of levels sometimes amounts to 2½ feet, but in general to 8 or 9 inches only.

Canals of Amstelland.

The Ye, before Amsterdam, is from eight to nine fathoms in depth, and forms a well sheltered road. The havens and canals of Amsterdam are shallow, being about eight feet deep at ordinary water. They are, therefore, fit for the Rhine ships and Dutch coasters, but do not admit vessels for foreign trade. These lie along the booms and front of the town, and the goods are transferred by means of the numerous canals of the city.

The several heights of the waters of Holland are referred to the Amsterdam Piel, which is considered to have been the mean height of the water in the Ye in the century before last; but that high water is now two or three inches above this level.

Without the walls of the city, the Amstel river is the great trunk of navigation. It is embanked and navigable eleven miles, to the boundary of the district at Amstelmondhard, by which it divides into two branches, which connect with numerous canals, both in this district and that of Rhineland. We are sorry that our bounds will not permit us to enter into further details.

Delftland.

The city of Delft is said to derive its name from "delvin," to dig. This jurisdiction is confirmed by charter in 1255. It contains three principal lines of navigation, uniting at the city. 1. The canal of Leyden, extending six miles to Leydsendam, with a branch of two miles to the Hague, and from thence six miles southward along the Downs, with various communications.

2. The Gasp and canal to Maesland Sluis eight miles, with a branch of five miles to Vlaardinger; one of four to Lice, and various small cuts.

3. The Schie 8½ miles to Schiedam, with a branch of 3½ miles to Vyfsluis, and two others, viz. one of three miles to the port of Delfthaven, and one of three miles to the city of Rotterdam.

Rotterdam is one of the chief ports of Holland, the Maese in front of it being 30 or 40 feet deep: It is accessible to large sea vessels. The sea lock at Delfthaven is worthy of attention.

4. The Watership of Woerden, and the Krimpen Waard, forms the central district of Holland, and dates from 1322. Its navigations are, 1. The old Rhine, in which are three locks, between Woerden and Utrecht; 2. The Linschotte, between the Rhine at Woerden and the Yssel at Ouder Water, with a more direct cut to Montfort; 3. The Wiericke, forming a communication in the lower part of the district.

Utrecht.

Besides the Rhine and Veght, Utrecht had, at an early period, formed several artificial canals. The Veght itself is said to have been united with the Rhine in 1148. A branch of six miles passes to Martendyke; the Vaartsche Rhyn is a canal of five miles from Utrecht to the Leck at Vreeswyck, and was made in 1373. The lock at Vreeswyck also dates from that period, and is, perhaps, one of the oldest on record. There are various branches from this canal, and these navigations are continued beyond the Leck, through the Betuwe, and to the Waal.

Southern Districts and Islands.

The southern districts of Holland being intersected by the arms of the Meuse and the Waal, have less need of artificial canals. Breda has a canal of some miles in length, into the great morass of Keil, for the carriage of turf; but the operations in this quarter have chiefly been embanking and drainage, and cuts for the improvement of sea-ports, amongst which that of Middleburgh, effected in 1532, is the most remarkable.

Considering that the polders are 18 feet below the ordinary low waters of the Meuse and Ye, and that the water of the embanked interior rivers are, in some instances, as in the Leck, 30 feet higher than the central polders of Holland, it will be seen that the situation of that country is truly critical; and the fact is, it has, at various times, suffered very materially from extraordinary inundations. Various plans have been proposed to prevent similar accidents, and one has been partially executed.

North Eastern Districts.

The eastern districts having a greater elevation, and being composed of a sandy barren soil, have fewer artificial navigations. The canal of Drusus, now one of the mouths of the Rhine, has already been noticed. The Berkel, which joins the Yssel at Zutphen, was made navigable for boats 25 miles, during the last century. At Zwoll a short canal has been made to the Veght; others proceed to the Yssel at Kampen, and further down on the Veght.

In Friesland the canals are numerous, a congeries of lakes passes nearly across the province south-west and north-east, and being almost all connected, form a very extensive navigation. There are, besides, many canals for the double purpose of navigation and drainage, every town almost having a direct navigable communication with each other.

The limits of this article preclude us from entering into further detail respecting the hydraulic works of this country; to do them justice a large volume would be required. The total of the hydraulic works between the Dollart and the Scheldt have been estimated, by a competent judge, to have cost 300,000,000*l.* sterling, and form, in so small a country, a most astonishing monument of human industry.

The Navigation of Belgium.

The early prosperity of Belgium had led to the early formation of inland navigations. Bruges was the great emporium of the north. This was owing partly to political causes, but chiefly to its situation on the first opening within the North Sea to ships from the ocean. At Bruges nature had, by the Lammens Vliet, between Cadsand and the Main, opened a deep navigable inlet into the interior of Flanders. Here was built the Port of Sluys; and from thence the ancient river was gradually embanked in 1130, and improved into a canal, reaching to Bruges, nine miles distant. Dam, between these, was formerly a sea port, and has still a separate canal to Bruges and Ghent. But in 1482, the quarrel between Bruges and the Archduke Maximilian caused the port of Sluys to be blocked up, and the seat of trade removed, first to Antwerp, and afterwards to Amsterdam. Bruges has still a noble canal to the port of Ostend, of 10 miles in length, capable of carrying vessels of 500 tons; it was enlarged and deepened in 1665 and 1728. Near Ostend are the great sea locks of Slykensas, built by the province in 1660. The Lieve was rendered navigable in the 13th century from Dam to Ghent, and in 1613 the grand canal of Albert and Isabella was begun, from the Lieve at Venderhout to Bruges. This forms the usual and direct route from Ghent to Bruges, 22 miles. It will carry vessels of 300 tons, and communicates at Bruges with the Ostend canal, 18 feet lower, by three locks. This line of communication continues along the coast to Calais. It is on one of those that the system of saving water by side-ponds was first practised, by Dubie, at the locks of Bousingue, of 20 feet fall (*Belid. Arch. Hyd.* vol. iv. c. 4. p. 411.) From Neuport the canal passes five miles to Furnes, where a communication is made by an overtoom, or double inclined plane. From Furnes, the canal, opened in 1644, proceeds to Dunkirk, where there are various branches. As, 1. The canal de Moores; 2. Canal of Berg, of five miles, admitting vessels of 200 to 300 tons; 3. Canal of Bourbourg, 10 miles, uniting with the Aa at Fintelle; and by the Aa to St. Omers, and by a branch to the Aire and the Lys; 5. Canal of Mardyke, two miles to the great sea lock, but the ship lock was destroyed in 1717. The river Aa has its outlet at the port of Gravelines.

There is another canal or river, called the Colme, from Furnes, through Berg, to the river Aa at Linke, 11 miles above Gravelines. This canal was made in 1662, under the Spanish President Castel Rodrigo, and communicates with Dunkirk by the canal of Berg, also by a branch to Hondsooten. There are also more navigable branches.

In a country frequently inundated, the formation of these water-courses became a matter of necessity, and was in general effected by the municipal authority of the several provinces or towns. This system continued in the low countries with little interruption until the period of the late Revolution, when the whole of these provinces fell under the dominion of France.

The Scheldt and its Branches.

From this brief view of the northern plain of Flanders, we shall turn our attention to the advantages which the southern and more elevated parts derive from the branches of the Scheldt. Near the ocean, the extensive marshes on each side are protected by high dykes, and it is only on arriving at Antwerp that the river, in a sudden bend, is found to reach high land on its eastern side. It is here the river is 30 feet deep at low water, and has 18 feet rise of tide, which carries the largest vessels up to the quays. The city is pervaded by several canals, which, since the destruction of its trade, have been arched over, and are only known as sewers. Two extensive floating basins, capable of admitting ships of the line, were constructed here by the direction of Bonaparte.

At Rupplemonde, eight miles further up, the Scheldt divides. The eastern branch, named Rupple, is navigable three miles to Mechlin, at the junction of the Senne, the Dyle and Nethes. As none of these admit of being navigated, except by craft of a small description, canals have been formed to Brussels and Louvain. The canal of Brussels was formed between 1550 and 1581, George Rinaldo being the engineer; it is 15 miles in length, with a fall of 50 feet by five locks. This canal is navigable for coasting sloops.

The canal of Louvain, formed in 1750, is 10 miles, and goes from Louvain to Mechlin. Half way between these places is a large basin or lock, with a fall of 10 feet, which requires half an hour to pass. There is also another double lock of four feet fall. The gates are 25 feet wide, and the length 96 feet. The canal has 10 feet water.

From Ripplemonde the Scheldt continues navigable by Dendermonde to Ghent, where it receives the Lys. The city of Ghent has also a direct communication with the sea by canals, as Bruges, Dam, already described. There are also various others, besides branches to different villages, especially the rich tract called the Pays de Waars, between Ghent and Ostend. Above Ghent the river Lys is navigable, by means of single sluices, to Cointray, Menin, Harebrouck, and Aire. From Lisle is a canal 23 miles in length, made in 1690. The Scheldt continues navigable above Ghent, by Oudenard and Tournay; it also receives the rivers Scarpe and Hairne, which are navigable to Douay, Anas, and Mons. The navigation of the Scheldt ceases, in a great measure, at Valenciennes, where a canal commences by Bouchain to Cambray, 16 miles. This forms part of the great canal of Picardy.

Various other projects of canals of junction were formed under the government of Bonaparte, but although some expense was incurred, nothing effectual was accomplished.

France.

Adjacent to Holland and the Low Countries, is the great kingdom of France. This extensive and singularly fine country, notwithstanding the example of Holland, &c. on the north, and Italy on the south, in regard of artificial canals, did not early adopt this valuable improvement. This neglect might arise from its being in possession of various great rivers, as the Rhone and Garonne in the south, and the Loire and Seine in the north, which, with the Rhine, and Scheldt, afford water-conveyance far into the country. Much must also be attributed to the character of the people, such as their being more disposed to grasp at apparently magnificent projects by great and hasty efforts, than steadily pursuing those more solid advantages which are accomplished by slow and imperceptible degrees. We accordingly find that most of the French canals, instead of being the result of the increasing industry of the people, have generally been the projects of ambitious princes. Charlemagne is said to have attempted to open a communication between the Rhine and the Danube, but he relinquished the undertaking; indeed, previous to the invention of the lock, it was not likely to be effected. Before the middle of the 16th century, Francis I. had formed schemes of inland navigation, particularly that of Languedoc, but no practical measures were then taken. This favourite project was revived under Henry IV. and his minister Sully, and they actually begun the canal of Briare, between the Loire and the Seine, although this last was only completed by Cardinal Richlieu under Louis XIII.

In the latter end of the 17th century, under the ambitious Louis XIV. the canal of Languedoc was accomplished, and an instructive example furnished France, and the rest of Europe, as to the means of obtaining improved inland navigation, over comparatively elevated and unfavourable ground. The most important of the circumstances which led, at this time, to the immediate accomplishment of this great work were, *1st*, Its being taken up by an ingenious Italian, named Francois Andreossy, well acquainted with locks, (sluices with double gates,) which, for more than 200 years, had been successfully employed in his native country; *2dly*, His having obtained the confidence of an able and enterprising intendant of the rich province of Languedoc, (Paul Riquet,) who was intimately acquainted with the celebrated minister of Louis XIV. (Colbert;) and *3dly* and *lastly*, This minister immediately perceiving, in this scheme, not only permanent advantages to the country, but a flattering object to his ambitious master. From Riquet having transacted all the business with the minister; having been sole contractor for the works; and his family, until the late Revolution, having enjoyed the revenue arising from the trade upon this navigation, the whole credit has, for more than a century, been exclusively attributed to him. Of late, however, General Andreossy has, in a very able treatise, vindicated the claim of his relation to the original design, and the plans of the several great works also, to the honour of superintending their execution, and, in truth, of having faithfully and perseveringly performed the office of engineer in chief, from the commencement of the operations to the opening of this extensive navigation.

Besides this very considerable line of communication in Languedoc, France has various others, which are equally extensive, and perhaps still more important. The rivers Loire and Seine have been connected by the canals of Briare, Orleans, and Loing. The Loire is connected with the Soane by the canal of the Centre. The Seine is also (to the southward) about to be opened to the rivers Soane and Rhine by the canal of Burgundy; while, to the north of Paris, it has been connected by the rivers Oise and Somme, and the canals of Picardy with the river Scheldt.

From this general sketch we shall proceed to give a cursory view of the inland navigation of each particular district, commencing at the southern extremity, thence passing along the eastern districts to the northern, from thence traverse the central parts, and lastly, notice those situated to the westward.

Of the more southern district, the canal of Languedoc forms the principal feature. From the account given by General Andreossy and others, it appears to have originated with Francois Andreossy in 1660, when he communicated the design to P. Riquet; that after having made a journey to Italy, he returned and continued to complete the survey and designs till 1664. The project was presented to the minister Colbert in this year, and by his orders the whole track and design, examined by M. Clerville, Commissary-General of Fortifications in 1665, who, in 1666, made a report, without mentioning the name of Andreossy. Riquet contracted upon this report and plan, although Andreossy had previously discovered its imperfections, and corrected his original design, and Riquet obtained authority to adopt this improved plan, by which the commissary was excluded from further interference. The first adjudication or contract, from the Garonne to 747 yards above the bridge of Trebes upon the Aude, was made to Riquet 14th of October, 1666. In 1668 Riquet requested leave to proceed also with the part of the navigation which was eastward of Trebes. M. Clerville also examined the country, and formed another defective project, which was accepted by Riquet under condition of being at liberty to improve it, which was done by abandoning it altogether for the more perfect one by Andreossy.

The track of the canal lies across the isthmus which connects the peninsula of Spain with the south of France, consisting of a sort of valley between the northern skirts of the Pyrenees and the Rhone. One branch of this valley passing in an easterly direction, is occupied by the rivers Fresquil and Aude, and leads from the summit of the isthmus, at Naurouse, to the flat shores of the Mediterranean, which are partly occupied by lakes, and partly cut through by rivers falling from the great mass of high land to the northward, called the Black Mountain. On the other side of the summit, the river Lers passes, in a north-western direction, to the city of Toulouse, on the great river Garonne, which falls into the Bay of Biscay a little way north of the city of Bordeaux. By this track, therefore, a communication by water is opened between the Mediterranean and the ocean, which avoids the circuitous and not unfrequently dangerous sea voyages around the whole of Spain by the Straits of Gibraltar.

With the view of supplying the summit with water, the Black Mountain was inestimable. Its extent of high land was great, and much of it covered with forests, which lessened evaporation. Facing the canal track, there were numerous streams sufficiently high to be collected and carried to the summit of the isthmus, which was accomplished by means of a drain or feeder ten feet wide at the bottom, and three deep of running water, taking in eight separate streams. Above three miles is cut in rock; and at Campmases, there is a tunnel 125 yards in length, and 9 feet diameter. It afterwards falls into the channel of the Laudot, which it follows three miles to the great reservoir of St. Ferréol. After leaving this, it continues in the Laudot until it joins the feeder from the river Sor. After which, they proceed across the plain in a feeder 12 feet wide, and 3 feet deep, of running water, to the basin of Naurouse. The whole length of these feeders is 38½ miles, although in a direct line only 17. The feeder across the plain was originally made for navigation, and had 14 locks; but these were given up, and used as a feeder only. There was at first an extensive octagonal basin or reservoir at Naurouse, 426 yards in length, by 320 in breadth, with 7 feet depth of water; but it has been long filled up with mud, and planted with poplars. The feeder now passes along side of it to the summit of the canal.

In giving a brief description of the canal line and works, we shall begin at the western end. The canal is connected with the river Garonne, below the mill-weir of Toulouse. It passes round the western side of the city, ascending by eight locks. After leaving Toulouse, the canal is carried along the southern side of the river Lers, ascending by 13 more locks to Villefranche, where it crosses the Lers, and rises by 5 other locks, making in all 26 locks, and 207 feet rise from the Garonne to the summit. The distance is 23¾ English miles; the summit level is only 3⅓ miles.

From the summit, the canal passes along the southern side of the valley of the Fresquil, beyond Castelnaudary, to the point where that river falls into the Aude near Carcassonne, having in this distance crossed the Treboul, and five smaller streams, and descended by 37 locks. On account of the inhabitants of Carcassonne objecting to the canal approaching their town, it was carried to the north of it. But in 1778, these ignorant men became sensible of their error, and proposed to contribute towards the expense of changing the line, so as to pass close to the town. This was adopted, and commenced before the Revolution. It was suspended, however, for some time, but has since been resumed, and probably completed.

After crossing the Fresquil, the canal passes along the northern side of the river Aude and the town of Trebes, to the commencement of the long level near the town of Olonzai. In this last distance, it has descended 22 locks, and crossed five streams, from the Black Mountain. The long level commences at the lock of Argens, near Olanzac, crosses the torrent Repudre, passes along the skirt of the mountain by Ventenac, and across the river Cesse, on the east side of which the canal of Narbonne branches off. The canal then proceeds, by considerable windings, to the north of Capestang, and around the point of the mountain Ecurene. It then crosses the narrow ridge of Malpas by a tunnel 181 yards in length, and proceeds to the top of the chain of 8 locks at Fonseranne. This level is 17 miles in length.—After passing this chain of locks and a single one, the canal crosses the river Orb, on the south side of the town of Beziers: it then takes a southerly direction, crosses the river Libron, and proceeds to the river Herault, north of Agde. After crossing it, and bending round the south side of the small lake Bagnes, it enters the western extremity of the large lake Thau, and through it passes to the port of Cette, on the shore of the Mediterranean. In this last distance there are 5 locks.

From the summit at Naurouse, to the port of Cette, the distance is 121¼ English miles, and the fall 62½ feet. The total length of this canal is 148 English miles. The lake Thau is about 9¼ miles in length, and 3 in breadth. The western end is so shallow, that the canal is carried 3¾ miles in it between artificial dykes.

Beyond the western extremity the river Garonne is difficult to navigate. Between Toulouse and Bourdeaux, a distance of 40 leagues, there are two places where boats drawing 20 inches water can scarcely pass in summer. In passing upwards the boats are hauled by 25 men, and require 15 days between Bourdeaux and Toulouse.

Originally there were only three aqueducts constructed, to carry the streams under the canal, all the others having been taken into it. But from 1681, when the navigation was opened, to 1688, the mischiefs from this were so evident, that M. Vauban, who, by direction of the king, examined the whole, recommended 52 more. The finest was that of Cette, of which Belidor has given a plate, and which has been repeatedly copied into French and English publications.

The greatest works on this navigation are, the reservoir at St. Ferréol; (see Plate CCCCXII.;) the basins at Castelnaudary; 102 locks, of which 8 are connected at Fonseranne, and one circular, 90 feet in diameter, at Agde; 55 aqueducts; the rafts and weirs across the rivers Libron, Orb, &c.; the tunnel through the ridge at Malpas; and 92 road bridges. In many of the bridges there were no hauling paths; and the locks vary in rise, from 5 to 12 feet. The canal, when perfect, is 64 feet broad at the surface of the water, 34 at the bottom, and 6 feet 5 inches deep. The first stone of the canal works was laid in April 1667, and the first voyage made upon it after it was completed, was on the 30th June 1681.

The vessels which navigate it are 85 feet long, from 17 to 19 feet broad, draw 5 feet 4 inches water, and carry 100 tons. They take from 6 to 7 days to go from Agde to Toulouse; but they do not travel in the night.

Canal of Narbonne.

Connected with the great canal is that of Narbonne. In 1664, the inhabitants contributed a considerable sum towards the expense of the great canal; but Riquet carried it immediately to the place of his birth, Beziers, with the view of reaching a better port at Cette. This canal of Narbonne now proceeds from the great level near Argelins, leaving the river Cesse on the right. In making this canal, much expense is unnecessarily incurred in placing the locks at regular distances from each other. The depth of the lake Sejean, from the mouth of the canal to the beacon, is from 4 to 6 feet. From this point commences the canal which the Romans excavated to the channel La Nouvelle, for the distance of about a mile and a quarter. The canal is carried round the flat shore of the isle of St. Lucie for about 3½ miles. The opening of the Grave varies in depth from 7 to 12 feet. There are seven locks upon this canal of Narbonne, and three upon La Robine.

To the north-east of the port of Cette, the canal de Grave commences, a quarter of a league from Montpelier, at Port de Juvenal, upon the Lez. In the three miles before it joins the lake Palavas, it has three locks; beyond that lake it joins a canal which proceeds to Cette, by the lakes Thau and Agde. There have been various projects for other canals here. From Aiguemort they now proceed to sea by the canal of the Great Robine, four miles to the Grau du Roi. They go to Pecais by the canal Bourgidon of five miles. The canal of Silvereal is 4½ miles, and goes from the Little Rhone to Pecais. The canal of Lunel is 4½ miles in length.

On the east side the Rhone, the Fosse Crapone, of 40 miles, is not navigable. Its engineer, the celebrated Adam de Crapone, about the same time, (1554 to 1558.) formed the project of uniting the two seas by the Soane and the Loire, which was begun by Henry II.

The canal of Provence, from the Durance at Aix to Marseilles, which would be 70 miles, was begun in 1752, but abandoned after three miles were cut.

The Rhone.

The canal de Lone, a new branch of the Rhone, about 10 miles in length, was made into a canal from a survey of Niquet, in 1706. It has, since that time, continued to be the principal branch.

Lalande is of opinion, that the navigation of the Rhone is always bad, because of the sand which is drawn to and lodged in its mouth, and is frequently shifting. At times there is not more than four feet depth of water, when an interruption is created for four months.

The canal of Arles was, in 1642, undertaken by a company of Dutchmen for drainage. In 1706, the inhabitants of Hieres began a canal named Ceinturon; it was discontinued in 1707, but has since been completed to Port de Buc.

The canal of Forez, between the Rhone and the Loire, has been partly executed under the name of the canal of Giver. Its summit would be 1211 feet above the Rhone, and 33½ miles in length. It commences at Givers, 10½ miles below Lyons, proceeds to the shore of the Gier, 8 miles from Givers. Not above one-third is executed; but this has 28 locks 80 feet long, and 15 wide.

There now exists between the lake of Geneva and that of Neufchatel, a canal which proceeds from Yverdun to near Venoge, a small river, which falls into the lake of Geneva, near Lausanne. From the lake of Neufchatel it would be easy to perfect the navigation of the river Aar, which falls into the Rhine. But the Rhone, in its present state, would render every communication imperfect.

In July, 1760, the brothers Perroud, engineers of the Republic of Valois, having represented to the French minister the advantage which would be derived from transporting red fir, &c. by improving the Rhone below Geneva, an inspection by French officers took place, from Le Fort l'Ecluse to Leyssel, but more especially at the great cataract, where the Rhone loses itself at the bridge of Lucey, near Bellegarde. The before-mentioned brothers proposed various projects, but nothing was done.

After the Rhone has left Geneva about ten miles, it enters between rocks from 100 to 200 feet high, and there loses itself. It disappears entirely at Bellegarde. Its fall is 207 feet in about 7½ miles. The floods from the rains and the melting of the snows upon Mount Jura carry down great quantities of earth and gravel. According to De Luc, the lake of Geneva is 1202 feet above the Mediterranean, where the river disappears 954, and at Lyons 538 feet.

The boats which navigate the Rhone are 64 feet long and 17 broad.

The canal of the Centre, or of Charolois, joins the Loire to the Soane; it departs from the Loire at Dijon, follows the banks of the Arrax, then the left bank of the Bourbince, passing by Parcey, Genelard, Airy and Blauzey, to the lake of Moutchamin, which has been made navigable, as has also that of Long Pendu, these lakes forming the summit level. From Dijon to the summit there are 30 locks, rising 240 feet in 6300 metres. The length of the summit level is 3940 metres.

The canal then descends by the left bank of the Dheune to St. Julian, where it crosses that river, and proceeds along the right bank by St. Benain, St. Leger, Deunevis, St. Gilles, and Remigny, to Chagny. At this place the canal turns to the right, and abandoning the valley of the Dheune, crosses towards Thalie, which river it follows to its termination in the Soane at Chalons. The descent from the summit level to the Soane is 400 feet, by 50 locks, upon 4700 metres distance. The whole length of the canal is 114,322 metres, or 71 English miles; the length of each lock is 100 feet, and 16 in breadth. The canal is 30 feet at the bottom, 48 at the water's surface, and 5¼ feet deep. The chief trade is wine, timber, coals, corn, and merchandize, in about 4000 boats annually. This canal was begun in 1783, and completed in 1792. M. Gauthey was engineer. Various extensions have been projected from the summit level of the canal, of which a small part only has been executed.

Canal of Burgundy.

The canal of Burgundy unites the Soane with the Seine; it was begun in 1775, and is still in hand; it is a rival to the canal of the Centre. It was in 1605 examined by Humphrey Bradley, an engineer of Brabant; by M. Riquet 1676, by M. Thomason in 1696; by M. Gabriel in 1724; and, lastly, by Messrs. Perronet and Chezy in 1764. The plans and reports of the two last are very able, and given much in detail, especially what regards specifications for the various necessary works.

But even after this report was made, some years elapsed before funds could be found. It was at length begun in 1775. The line ascends by the rivers Seine, Yonne, and Armanson, to Brienon, to which place these rivers are navigable, and it is here that the canal commences; it proceeds along the right bank of the Armanson, by St. Florentin Tonnere, Ancy Le Franc, and Baviers, to Moulbard; then crossing the river, and ascending the left bank, it afterwards leaves this river for some time to follow the right bank of the Brenne to Pouilleray, where it again passes over to the Armanson, and follows that river to its source, near Pouilly, where the summit level will be 888 feet above the junction with the Yonne, and 674 feet above the Soane. From Pouilly the canal is to descend by the valley of the Ouche to Pont de Parry and Dijon, and thence by the plain of Longe Cour to St. Jean de Lone, a town upon the river Soane.

In 1814, this canal, which, previous to the Revolution, had been carried on by the states of Burgundy, was resumed under Bonaparte, and was navigable on the side of the Soane, from its commencement, to Pont de Parry, five leagues west of Dijon, in all 13 leagues. On the side of the Yonne the navigation was opened about as far as Ancy le Franc. The whole length of the canal would be 148 English miles. Up to Parry 23 locks were made, but the disposition of the summit remains undecided.

Franche Compte is traversed by the Doubs, which rises on the side of Montbelliard, at a small distance from the Rhine, and falls into the Soane at Verdun; this might be joined to the Ill, which falls into the Rhine at Strasburgh, by a canal of about 18 miles only; or a canal might be carried from the Doubs immediately to the Rhine, a track of about 42 miles. The point of partition, of the first canal, would be about 12 or 15 leagues to the south of the place where the Roman General Vetus proposed to join the Soane and the Moselle; but the navigation of the Doubs requires to be improved.

In Alsace, the canal of Malsheim, five leagues in length, with 11 locks, was made by the order of Louis XIV. from a plan of Vauban. The canal of Landau joins the Rhine with the Quick above Spires. The canal of Drussenheim, made in 1706, passed by a branch of the Ill from the Rhine. There have been various projects for canals in Alsace.

There have also been many projects for canals in Lorraine and Champagne, but our limits will not permit us to describe them.

The boats of Liege are 115¼ feet long, 15 broad, and four feet three inches deep. They could be drawn up the Meuse by two horses, and go from Liege to Paris. The Barois boats are 85 feet long, 11 feet 9 inches broad, and 3½ feet deep. Three horses draw two of these boats from the Meuse. The boats upon this part of the Meuse are 107 feet long, and 14 broad. They generally pass three and three.

Among the rivers which fall into the Marne, is the Canal d'Ourcq or Ourque, in the Valais, to the east of Paris, between Meaux and Soissons. This is only the river Ourque, rendered navigable in 1662 for 20 miles, to supply the city of Paris with water and turn cornmills. Part only of the canal is made.

The river Seine is navigable only to Nogent; it was once navigable to Polissy, 25 miles above Troyes, and five above Bar sur Seine. In 1727 the Sieur Gaillet stated, that until 1720 it had been navigated without interruption, but that, since the king became proprietor, it had been much neglected; that undertakers, having re-entered in 1727, they had in the same year repaired the canal Sauvage, and also most of the other canals. In their contests with the merchants they stated, that in 1725, the receipts amounted to 547,482 livres, and the expenses 1160,267, being an excess of 612,785 livres, and that during 46 years they had drawn no interest for the capital expended. It appeared in the process verbal of 28th August, 1746, that the canal Bruley was partly fitted up; that the canal of Fouchy, of 1½ mile, was sufficiently well supported between the gates, but these being at the extremities, were destroyed; that the canal Barbeny was ruined; that the canals of Biance and Payens, of 2¼ miles, were inaccessible, and that there remained few vestiges of bridges or gates; that the canal of Savien was nearly destroyed, and planted with willows; that those of Mesmon and of Marigny were in the same state; that the canal Sauvage had one lock destroyed; that the canal du Pont was partly filled up and the lock destroyed; and that the canal Nogent was choaked up at the head, and the gates destroyed. From all these circumstances, the engineer concluded, that the navigation from Troyes could not be supported, and that there was no business at Troyes to remunerate the expense.

In descending the Seine towards Paris, there is the small river Voulsye, which never freezes, and here are the vestiges of an ancient canal, supposed to be made by the Romans. The demands of Paris have rendered canals desirable, but in all the projects the expense has always been found to be too much. In 1724 it was proposed to make a canal from Paris to the river Oise, near Isle Adam, to Meny sur l'Oise; the high water of the Oise at Vaux is 3½ feet above high water of the Seine at Paris. But this project was rejected by the magistrates of police of Paris in July 1730. (See Lalande.) There was a project to make a canal from Versailles to the Seine at Sevre. The fall was found to be 387½ feet.

The Seine below Paris has much need of improvement. In 1768 and 1769, Captain Berthollet made four voyages from Havre de Grace to Paris, with the ship St. Ouen, of 160 tons, which had one mast of 96 feet, with a joint for passing the bridges; he employed four days in ascending to Poissey, which is only 12 miles from Paris, and three days in going from that place to Paris. He sometimes employed sails, and sometimes horses.

The Seine, from its mouth to Rouen, is incommodious; and the numerous beds of sand are constantly shifting. In 1747 the change was so favourable, that the flux and reflux became sensibly stronger above Rouen; but, in a memoir of the same year, a complaint is made that the commerce of Rouen had decreased one half from the imperfection of the navigation. It has been proposed to deepen the river by machines, and patents were granted; but the progress was small and the expense great. It has also been proposed to deepen by floating jetties.

The river from Rouen to Paris is navigable only four months in the year. The great boats of Rouen are 191 feet long, they carry 350 tons, are drawn by 12 horses, and take 18 to 20 days in going to Paris. The small passage boats take at least five days, but more generally 12 days. It has been found most advisable to employ boats drawing from three to five feet water. Three locks have lately been constructed upon the Seine, viz. one at Pont de l'Arche; another at Isore; and a third at Vernon.

The Oise receives the stream Venettes half a league below Compiegne; the sand bars the mouth so much, that boats are obliged to be lighted. Corn and wood are carried upon it in half loads. In 1766 the boatmen of the Oise gave in a memorial to have it cleaned to Verbine.

In Picardy two canals have been completed, and a third begun. That from the Oise to the Somme, named also the canal of Fere or canal of Crozat, was finished in 1738. M. de Marcy, in 1721, proposed a canal from the Somme to the Oise, which, near St. Quintin, are only 10 miles apart. By an edict of September, 1725, the king appoints M. Caignart, and assistants, to construct a canal between the Somme and the Oise, to commence at the lake of St. Quintin, passing Harly, Hambliers, Marcy, Regny, and Sissy, near Oise, to Fere; to deepen the river Oise from Sissy to Chalney; and to render the Somme navigable from St. Quintin to Amiens, and from Amiens to Perpigny. In 1727 operations commenced by a company, to which Regimorte was engineer; but it appeared that the best line had not been chosen, for in 1732 the line was carried past Virey, Condrun, Fargnier, Quessy, Liez, Menessies, Jussy, and St. Simon, to Pont and Thugny sur Somme, the point of partition. The plan was published in 1732. (See Belid. *Arch. Hydraul.* b. iv.) From St. Quintin to La Fere the distance is eight leagues; from Fere to Chaulney on the Oise, by the canal, three leagues; from Chaulney to Sampigny, by the river, five leagues. In 1766 the king was requested to purchase the canal of Picardy, or suffer it to be destroyed, and the materials sold. The king became purchaser. The canal between the Somme and the Oise was begun in 1728, and finished in 1738. In 1768 and 1769 M. Laurent examined the state of the Somme, and in consequence of an arrêt of council, May, 1770, improvements were commenced between St. Simon and Ham. In 1771 the river could be navigated between St. Simon and Clery, three miles below Peronne, that is, including windings, about 20 miles, or one half the navigation; the channel of the river being crooked, much use could not be made of it, a canal was therefore excavated, chiefly along its sides. Below the ancient city of Bray, the canal entered the bed of the Somme, and continued in it past Corbie, eight miles to Amiens. In 1777 operations were recommenced by Dupliex. In truth, the Somme, which was formerly navigable above St. Quintin, now ceases to be so below it, and they have been obliged to substitute a canal. The mouth of the Somme is also much obstructed.

The third part of the canal of Picardy consists in joining the Somme to the Scheldt, between St. Quintin and Cambray, continuing along the Scheldt, by Crevecoeur, Cambray, and Bouchain, to Valenciennes, where the Scheldt is navigable. In 1766 M. Laurent thought a canal could be made for twenty millions of livres, and judged it practicable to make a communication by a tunnel, which should be seven miles long; and this plan was commenced. The head of the canal was fixed at the village of St. Simon in Vermandois, near St. Quintin; beyond that it extends towards Couchant, and enters the mountain four miles from St. Quintin, to proceed to the Scheldt at Vendhuille, distant seven miles, and 10 from Cambray, in a straight line. In 1767 the plan was approved, and in February 1768 the work was begun, viz. the earth work or excavation from Vendhuille to Benthall, and from Trongusy to St. Quintin, and the entries of the tunnel. In February 1769, M. Laurent was appointed director-general of these works, likewise to render the Scheldt navigable to Valenciennes; but the expenses of the state interrupted the payments. In 1772 and 1773 funds were procured, and considerable progress made, with opening wells, drains, &c. and constructing a part of the tunnel. They proceeded carrying forward the tunnel towards Trongay, as they had in 1768 proceeded from it. The breadth of the waterway was to be 17 feet, besides a brenching on each side of two 2 feet 1½ inches, making 21 feet 3 inches, and 21 feet 4 inches in height, from the bottom of the canal to the crown of the arch; the depth of the water to be 5 feet 4 inches.

In 1773, objections were raised against this line of canal and tunnel. In the mean time, M. D'Alembert, the Abbe Bossut, and M. Condorcet, having been appointed directors of Inland Navigation, thought proper to have the matter thoroughly examined. In 1775, M. Trudaine gave notice, that the tunnel operations would be suspended. In 1800, the first consul (Bonaparte) personally examined this tunnel, and ordered a fresh inspection of it by the engineers of roads and bridges. The report was referred to the Institute, who decided in favour of the ancient plan of Devic, and an arrêt in 1801 confirmed this decision—that is, that the canal should proceed by Omini, Le Tronquoi, Bellinglise, Riqueval, and Maquincourt, and in that direction it has been completed in 1810. The length of the canal is 32 miles 1151 yards. It is fed by the Somme and the Scheldt, from St. Quintin to the point of partition.—From the junction of the canal Crozat to the lock of Tronquoi, at one end of the summit, the rise is 33 feet 6 inches by five locks. The summit is 13 miles 435 yards, including two tunnels, viz. Tronquoi 1191 yards, and that of Riqueval, 3 miles 1026 yards. These tunnels are 26 feet 3 inches in width. From this end of the tunnel to Cambray is 15 miles 694 yards, with a fall of 123 feet 6 inches by 17 locks, each of which is 97 feet long and 17 broad.

From this northern extremity of the kingdom we shall now pass to that district situated between the Seine and the Loire, where the first important project for inland navigation in France was executed, that is, the canal of Briare, begun in 1605 under Henry IV. The engineer was Hugues Cromier. Operations were suspended in 1610. In 1639 the works were resumed, and prosecuted until they were completed in 1642. It is 34¼ miles in length. It commences in the Loire, a mile from Briare; ascends by Ouzonne, along the banks of the river Trezec, by Rogny, where there are seven locks. Thence it proceeds by Chatillon and Montargis, and near Cepay joins the river Loing, which falls into the Seine. The locks of this canal are the first which were executed in France; they are supplied with water from several lakes, between Chatillon and Briare, on the side of Rogny. There is only one feeder, which has proved insufficient; for boats drawing only 2½ to 3 feet water have frequently to be lightened. The breadth of the canal is unequal, being from 25 to 32 feet at the surface. The locks are from

124 to 164½ feet long, 14 feet 5 inches in breadth; and vary in rise from 5 feet 4 inches to 13 feet 8 inches.

		Feet.	In.
From the Loire to the summit, the distance is 9 miles, the rise		126	4
The summit level is . . .	3¾ do.		
From summit level to Loing at Montargis,	21½—the fall	259	
	34¼		

The feeder of St. Prive, in a distance of 12 miles, has a fall of five feet only. The boats are drawn each by two men. The navigation is every year interrupted, not only by the repairs, but the shallows of the Loire, and that not unfrequently for three months. Each canal-boat carries from 100 to 115 milliard, and draws from 28 to 30 inches of water. There are 25 lock-keepers, one general guard, and 11 others to watch the canal, lakes, and feeders. The lock-keepers, &c. are chosen from masons, carpenters, and earthworkers.

The canal of Orleans originated from the imperfections of the canal of Briare, and the difficulty of ascending the Loire 36 miles above Orleans to reach it. In 1680 an arrêt was registered to permit a canal to be made from the Loire, a little below Orleans, to the river Loing, below Montargis. The work was begun in 1682, and prosecuted until 1684. It was then stopped in 1688. The house of Orleans, who had originally proposed the canal, now re-entered, upon paying the company a rent of 15,000 livres. The canal is supplied from numerous lakes by feeders, one of which, Courpalet, is 19½ miles long, and, according to Regimorte, has only a fall of four feet. The total length of the canal is 45 miles. It has 28 locks, varying from 136⅓ to 177¼ feet in length, and from 5 feet 4 inches to 12 feet 7 inches in rise. From the Loire to the summit, the rise is 98 feet 2 inches; from the summit to the Loing, the fall is 137 feet 7 inches. The breadth of the canal is generally from 25 feet 7 inches to 32 feet at the surface of the water. The depth is 4½ feet, when full, to 2 feet when lowest. The boats are from 96 to 102½ feet in length, and 13 feet 10 inches in breadth. It is said that this canal has been much neglected. Regimorte made many repairs in 1725 and 1726.

This is a prolongation of the canal of Orleans and that of Briare, from Montargis to the Seine, at the small village of Mamort, near the city of Moret, being a distance of 33 miles. Letters patent for improving the river were granted in April 1720, and the works were completed in 1724. The canal is generally 44 feet at the water surface, and 34 at the bottom, with four to five feet depth of water. On each side there is a towing path, 6 feet 5 inches in breadth. Three feet above the hauling path there is an embankment, 19 feet at the base, and 12 feet 9 inches at the top, to prevent the floods from overflowing. Regimorte was the engineer. It enters the river in various places. It has 21 locks, with a total fall of 136 feet 3 inches. The locks vary in height from four to seven feet, and in breadth from 15½ to 16 feet.

In Normandy, Poitou, and Bretagne, there have been many projects for canals, but none have been executed. The rivers are, at the same time, very imperfect navigations. In 1746, complaints were made, that upon the banks at the mouth of the Loire there was only seven to eight feet of water. The Allier, which falls into the Loire, has not more than 40 miles of good navigation. In general all the provinces have rivers, which have either ceased to be practicable, or are too precarious to be useful.

This canal is formed by the river Layon being rendered navigable 35 miles, from Concourson to its mouth in the Loire at Chalonne. This canal begins between Concourson and St. George; is 25½ feet in the narrowest part, and 43 in the broadest. It has 28 locks. It was opened in 1776.

The river Charente is useful in several provinces for 60 miles. In 1772, M. Tresaquet was employed to form a proper plan for improving this river. The work was begun at Sicray in Poitou, 35 miles north of Angouleme, and 25 south of Poiters, with three locks with chambers, and 70 small sluices with portes busques. In 1777, six of the latter had been constructed, admitting boats of 60 tons, which pass these pertuis of 3 to 3½ feet fall, by the help of a capstan worked by six men in ten or twelve minutes. The ancient pertuis were very troublesome and dangerous, but Tresaquet greatly improved them, as will be explained hereafter. The gabares upon this river are from 101 to 104 feet long, including rudder, and 19¼ feet broad.

The river L'Isle is navigable from Liboime, where it falls into the Dordogne, to the port of Fourche, near Courtras, where it receives the Drone.

The Lot, which descends from Gevauden, and falls into the Garonne below D'Agen, at Equillon, has 12 sluices.

Lalande observes, (p. 419.) that the slopes of the French rivers are well adapted for navigation; but that, at present, it scarcely exists, even in the large rivers; and that the navigation of the Seine, from Rouen to Paris, is so tedious as to cause land carriage to be preferred. Lalande's book was published in 1777.

Spain.

This great peninsula is in no respects distinguished by its inland navigation. Anciently the theatre, where the most ambitious powers contended for empire, Carthaginians, Romans, Vandals, Visigoths, Moors, and Christians, have successively been its rulers. In later times it has been distracted by the contentions of separate kingdoms, as well as by a too frequent change of dynasties. The acquisition of South America has also been inimical, as well as the habits arising from political and religious establishments.

The country, being composed of great valleys, divided by rugged mountains, is no doubt unfavourable to inland navigation; but, if industry were properly encouraged, these apparent obstacles would be surmounted, and communications established between the hitherto unconnected districts.

The following brief sketch exhibits rather the general intentions respecting inland navigation, than what has been really accomplished in Spain.

Commencing in the southern parts of the kingdom, we find the Moors had opened a canal from the city of Grenada to the river Guadalquivir, and had, of consequence, formed a communication with the Gulf of Cadiz. By a chart published in 1776, it appears that a canal was proposed in the province of Murcia. Its length, from its commencement at the river Gualantin, to its termination at Carthagena, is 103 miles in a direct line. This canal, though commenced, was, we understand, abandoned.

In the interior of Spain a canal was planned in 1784, to proceed from near the Escurial to the Tagus and the Guadiana, and, finally, to terminate in the Guadalquivir Auduxa. It was planned by Le Maur, a Frenchman.

It was afterwards prosecuted by his sons; but we suspect little progress has been made. Another canal was begun under the administration of M. Grimauldi, to open a communication between the Tagus and the river Manzanares; but it was scarcely commenced, when the want of means restrained it to the supply of a few mills, about ten miles in length being all that was executed.

It is in the north of Spain that the chief canal operations have taken place. The line projected in Old Castile, exclusive of the principal branch to the cities of Castile and Leon, from Segovia to Olea, (a small village near Reynosa,) is about 99 miles in length.

In the province of Campos, to the west of Pisuerga, another canal has been projected, to pass by Medina de Rioseco, and at Grisotu would unite with the canal of Castile. In 1754 it was commenced. As the canal of Campos would be very imperfect without the canal of Castile, the king, in 1750, ordered the former to be interrupted, and the northern part of the latter commenced, by taking the water from Pisuerga, and continued to the canal of Campos; and 18 miles have actually been made, and 14 locks.

The imperial canal, projected by the Emperor Charles V. was not properly begun till 1770. It was to be carried along the vale of the Ebro, and ultimately to the Bay of Biscay. It should receive the waters of the Ebro at Tudela in Navarre, and from that place descend towards Saragossa and Quinto. An open cut has already been made across a mountain eight miles in length, and 203 feet high. (See Lalande.) The cut is 38½ feet in breadth, and has 6 feet 5 inches of water. Charles V. had attempted to penetrate the mountain by a tunnel; but though the work fell down, and the enterprise was abandoned, the project has retained the name of the Imperial Canal.

The designs we have here described are not unfrequently more extensive than practicable, and in some instances more practicable than useful. They have been more the projects of speculative statesmen than the suggestions of general prosperity, and seem to have been rather contemplated as excitements to, than produced as the results of useful industry.

Germany.

This large portion of Europe has been so long divided into intricate local jurisdictions, that no extensive inland navigation could be accomplished; yet, notwithstanding many local vexatious obstacles, Germany, by means of its fine rivers, enjoys a very considerable inland navigation, and even some artificial canals.

Charlemagne conceived the project of uniting the Rhine with the Danube by means of two small streams near Nuremberg; one of which falls into the Main, the other into the Danube. He actually deepened one of them two miles; but the project was abandoned.

The great channel of trade from the north to the south of Germany has always passed nearly in this line.

Charles V. proposed uniting the Danube with the Elbe by means of the Moldwa; but this scheme yet remains in embryo.

Switzerland and the Rhine.

In Switzerland, a company of Dutchmen and others began the canal of Yverdun. The objects were, to drain marshes at the head of the Lake Neufchatel, and form a navigation from thence to the Lake of Geneva, near Lausanne, thereby connecting the Rhine with the Rhone. Twelve miles of this navigation were completed; but France, possessing Alsace, objected to its extension, so that it is now only maintained to Entre Roche, about nine miles. It is about 25½ feet in breadth, and has twelve locks. Boats pass from it through the lakes of Yverdun and Bienne to the Aar, which is navigable to the Rhine.

Descending the Rhine, we meet with the canals of Alsace, which have been already described under France. After them, excepting some short cuts, such as one of 3 miles from the Rhine to Franthal, near Manheim, made in 1775, and another from Durlac to Carlsruhe, we find nothing worthy of notice till we reach the frontiers of Holland.

In this place we do not propose to enter into the details of the navigation of the great German rivers, which will be found under their proper names. The Rhine is navigable from Switzerland to the sea. The current is generally rapid, sometimes four to five miles an hour, even as low as Dusseldorf. The principal descending trade begins at Basle. The only remarkable obstruction below that place is at Bingon, where a reef of rocks runs across the channel, leaving a passage of nine or ten yards only for boats during low water. The floods of the Rhine are gentle, but of long continuance, being regulated by the lakes of Switzerland.

Few loaded boats ascend to Basle, on account of the rapid currents and want of towing paths; but the large Dutch boats come to Strasburgh. They are 120 feet long, 12 feet broad, and eight feet deep in the hold. They draw six feet water, and, when loaded, draw 150 tons. In tracking, eight horses, four conductors, and six boatmen, are employed. They descend with oars, having nine boatmen and three pilots.

Cologne is the chief seat of the commerce of the Rhine, the goods being transhipped there into large vessels, called Cologne ships, which navigate to Holland, and are of the burthen and rigging of Indiamen, although they seldom draw above five feet water.

At Rastadt the Rhine receives, by the Marg, the great floats and rafts from the Black Forest. The Neckar, the Mayne, and the Lahne, are also collaterals. The vessels used on these rivers are long, and very narrow, and of about 30 tons burthen.

The Moselle is navigable for large Rhenish barges from Coblentz by Treves, to Metz in Lorraine. At Metz there is a transhipping into lighter vessels, to ascend to Nancy.

The Meuse not being connected with the present subject, we proceed to the Danube in Austria. This magnificent river affords a navigation of about 1500 miles. Below Belgrade the river is interrupted with cataracts, but upwards there is a free navigation as far as Ulm. The upper branches of the Danube are in general too rapid for navigation, though vast rafts of timber are floated down them from the forests of Bavaria and Upper Austria. The Inn is nearly as large as the Danube at their junction, and is navigable from the Tyrol. The Salza, the Traun, and the Ens, have had their navigation much attended to, on account of the salt mines. At Ischel, below Hallstadt, is a pertuis, or river lock, by which the navigation is enabled to pass the Falls of the Traum. The boats are towed upwards by four horses each. Below the influx of the Traun and the Ens are rocks and whirlpools of Stroudel and Wirbel; but the

Danube continues, in general, a deep and unobstructed river as far as the city of Vienna. Regular passage boats travel weekly from most of the towns on its banks to that city. Beyond Vienna the river divides into various channels of less depth, which do not again completely unite until it reaches Komorn in Hungary.

The chief branches of the Danube are also navigable to a great extent, viz. the Drave into Carinthia, the Save as far as Laybach. In Croatia the Kulpa is navigable from the Save at Siszeg to Carlstadt. The Unna, on the frontiers of Turkey, is also navigable.

A good deal has already been done in the interior. From Vienna, the canal of Newstadt passes for 40 miles southwards, to the town of Wiener Newstadt on the Leitha; and forms the first part of the general line of navigation to the Adriatic and lower Danube, which has been planned and marked out.

In the lower plains of Hungary, between the Danube and the Teysse, the canal of Francis was completed in 1802. It is 40 miles in length, and has only four locks. Beyond the Teysse, and near to the outfal of the Francis canal, are the Bega navigations, which were completed in 1750, from the Teysse to Temeswar, and thence up the Temes river.

The Teysse itself is navigable up to Szegedin, where it receives the Maros; and about 100 miles above the canal Francis, another canal of junction was laid out in 1804, and 50 miles extent, from the Teysse to the Danube at Buda.

Many other canal projects have been suggested, and some surveyed, but, as we cannot here enter into the details, we shall now proceed to the north of Germany.

Prussia, Elbe, Oder, &c.

The great plain which forms the north of Germany and Poland, offers an extensive and favourable field for inland navigation. It is traversed by five or six large rivers, which, with their branches, are navigable throughout most of the plains. In the northern parts is a vast number of lakes; and though these admit of being easily connected, nothing of any importance was effected previous to the formation of the Prussian monarchy.

The little canal, or navigation of the Stecknitz from Lubec to the Elbe at Lauenburg, is a work of considerable antiquity, and reckoned amongst the first in which the invention of locks was employed. It is only navigable by boats of small burthen, and drawn by men.

The Prussian navigations form a complete chain, connecting the Elbe, Oder, Vistula, and the Niemen, by a line nearly parallel to, and 100 miles distant from, the shores of the Baltic, and at much the same distance from the frontiers of the Austrian States. This line passes through the capital Berlin, and extends from Hamburgh, or Magdeburgh, to the frontiers of Russia; in all about 500 miles. The greatest part consists of rivers, the artificial cuts being only a few portions of no great extent or lockage.

The western part of this system is the river Elbe, navigable from the frontiers of Bohemia: At Leutmeritz it carries small boats; at Perna, above Dresden, it admits river barges; from Perna to Hamburg it has an unobstructed navigation of upwards of 300 miles; and 70 miles lower it falls into the North Sea. Of its branches, the Havel is the only one worthy of notice; it rises on the borders of Mecklenburg, runs southwards to Spandau—near Berlin it receives the Spree, when it becomes navigable for vessels of considerable burthen; from Spandau it passes to Potsdam and Brandenburgh, into the Elbe at Havelburgh. To improve this river, in 1743—5, Frederick II. caused the following works to be constructed.

1. The canal of Plauen, from the Lake of Plau at the bend of the Havel near Brandenburgh directly to the Elbe, by which the navigation to Magdeburgh is shortened 76 miles. The canal is only 17 miles long; the fall to the Elbe is 23 feet; by three locks; the width is 26 feet. The engineer was Mahistre.

2. The canal of Potsdam—a cut to shorten the navigation of the Havel.

3. The canal of Finaw, from the upper part of the Havel, 20 miles north of Berlin, to the Oder at Odersburg. It is 23 miles long, falling 130 feet, by 13 locks. It was begun in 1605, but was only completed in 1751.

4. The Muhlrose canal from the Spree to the Oder. This was the earliest in Prussia, having been finished in 1688, with 10 locks of wood. The engineer was Philip de Chiese. The locks were afterwards reduced to 8, and built with stone by king Frederick I. It is 23 miles in length; it ascends 10 feet, by one lock, to the summit level, and from it, descends 64 feet, by 7 locks, into the Oder, five miles above Frankfort; the width is 60 feet, depth 11 feet.

The Oder is navigable from the Baltic to Brieg in Silesia, above Breslaw, being about 300 miles. At Kustrin it receives the Warta from Poland. Below that a cut named the New Oder was made in 1753, and a dredging machine, wrought by a steam-engine, has lately been procured in London, to deepen the bar at the mouth of the river.

The Warta is navigable for 200 miles into Poland; the main navigation passes along the branch named the Nitza, as far as Nackel, where commences the Bromberg canal, constructed in 1772—5, by Frederick the Great, and the engineer Breckenhaff. It is 16 miles in length; its fall from the Netze to the Brahe at Bromberg is 67 feet, by nine locks. The navigation is then continued by the River Brahe to the Vistula between Thorn and Culm.

The Vistula is navigable from Austrian Gallicia to the Baltic at Dantzic, nearly 400 miles. Its branch, the Bog, 100 miles, and as much by the Narau. By these the produce of Poland passes down to Dantzic in sloops and flat-bottomed barges of from 30 to 60 tons.

Dantzic communicates with the sea at its harbour of Weichselmunde, by a cut called the Fairwater. The Delta of the Vistula between Dantzic and Elbing, and as high as Marienwerder, is an embanked country, intersected by many navigable cuts. The main body of the river falls into the Frische-Haff, by which the inland navigation is prolonged to Konigsburg, on the Pregel, which river is also navigable 30 miles further to Welaw, and serves for the floating of timber much higher.

The Pregel is supplied from a multitude of lakes in East Prussia. To improve the drainage of these, the canal of Angerburg was made in 1725. The Sapian canal was made at an early period; also a series of cuts, to prolong their navigation to the Niemen below Tilsit, about 1690.

Various projects have been suggested to form a communication between the Baltic and the Black Sea, by the branches of the Vistula and the Dnieper, but nothing has hitherto been effected, except the canal of Pinsk, begun in 1766. It commences in the Iasiolda, which falls into the Prypiez, and thence into the Dneister and

Black Sea, and terminates above Slonim in the Stchara, which falls into the Niemen and the Baltic. A lake of three miles, which the canal traverses, supplies the lockage. It was made navigable in 1784, but not quite completed till 1802.

In the same quarter was formed the river Pina from the Dneister to the Muchawicz and the Bug, and thence to the Vistula. It was opened in 1784, but has hitherto been little used.

Hanover.—The Weser.

Both the Ems and the Weser are navigable; the former to above Lingen, from which a canal proceeds 20 miles to the city of Munster. The Weser is navigable to Hoxter, near the Hartz mountains, about 100 miles from the sea, and 60 from the port of Bremen. The only branch of note is the Aller, which admits boats to Zelle. The Leine is also navigable to Hanover. There are various improvements by cutting off bends.

Denmark and Holstein.

The ancient canal of Stecknitz has already been mentioned in the description of Prussia.

The canal of Keil unites the Baltic with the river Eyder, which falls into the North Sea below Toningen, and thereby forms a short transit across the isthmus of Jutland. This canal was begun in the year 1777, and finished in 1784. Its length is 22½ miles; breadth 100 feet at top, and 54 at bottom; depth of water 10 feet, and it admits vessels of 120 tons. It commences three miles north of Keil, at the mouth of the Lewensawe; it rises 27 feet, by three locks, to the summit level, when the Hemhuder lake supplies lockage water; it falls thence by two locks of eight feet each, and a regulating lock (at Rendesburg) of 5 to 7½ feet, into the Eyder. The locks are 100 feet long, and 27 feet wide. The Eyder continues navigable from Rendesburg, 82 miles to Tonningen on the Ocean, but is much obstructed by shifting sands.

Russia.

This vast empire has, at all times, enjoyed, by means of its numerous great rivers, a navigation of great extent and importance. The artificial improvements had their origin from the Czar Peter, whose ardent and comprehensive mind not only conceived these projects, but in person examined, and, on the ground, determined their outlines. Even after his defeat at Narva, he immediately planned the junction of the Baltic with the Caspian and Black or Euxine Seas. During his travels, amongst many other laudable actions, he engaged ingenious persons to plan and conduct his projected inland navigations. In 1698, colonel Brecknell, a German, was employed to form a communication between the Volga and the Don, the czar having at that time an idea of fixing his capital at the mouth of the latter; but, either from the colonel's want of experience, or the incapacity of the workmen employed, the operations which he attempted failed, and he clandestinely left the country. In the same year, the czar, being in England, engaged captain Perry for that and similar purposes. When he reached the place where colonel Brecknell had been at work, he found the only lock in which he had been employed in ruins. The czar had ordered 30,000 men to be put under captain Perry's direction; but not one-half ever arrived. The governor of the province, and boyards of the country, were very averse to improvements, and contended that it was presumptuous to attempt changing the course of rivers, which were assigned to them by heaven. Indeed, the project appears to have been premature. In 1702, Perry was ordered to suspend his operations in that quarter, and was sent to Varenetz, on the Don, to construct a dock for repairing large war vessels. Here he was employed until 1708, when the czar, proceeding rapidly with his new capital at Petersburgh, began to be sensible that it was necessary to open water communications, to carry supplies of food, &c. from the southern and eastern provinces. Captain Perry was directed to survey the country, in order to ascertain the best lines of communication between the Neva and the Volga. He made a regular survey of three lines, and of these two only have yet been effected, in an imperfect manner. That to the north has the difficulties of the lakes Onega and Ladoga, and that to the south being carried along shallow rivers, which are only rendered navigable by flashes. The central line, though most direct, is the highest, and at its summit there is a land carriage of 80 versts. But it is most probable that the inland navigation of this country will always be mostly upon natural rivers, and here, as in other northern countries, during the winter months, there is a convenient and useful land carriage, in every direction, over the snow and ice.

The invention of steam boats will probably, in time, go far towards correcting the inconveniences of river navigation, and will therefore be an important acquisition to Russia. The experiments already made upon the Neva and Volga, by Mr. Charles Baird, a Scotsman, confirm this opinion. The Volga is navigable from the Caspian for 2000 miles to Rchef, 130 miles north-west of Moscow; to Orel, on the Oka branch, and to Moscow; to Vishnie Voloohok, nearly midway between Moscow and Petersburgh; to Sominska, near lake Onega; and also to a great height in the Kaura, the Vatshka, the Una, and other intermediate branches. It thus forms a navigation through an equilateral triangle, 1100 miles of a side.

Astracan is the natural port of the Volga, from which a voyage to Petersburgh occupies about two years. A range of comparatively high country runs along the eastern side of the lakes Hunen, Ladoga, and Onega, dividing the waters of the Neva from the Volga. Captain Perry levelled a line at each of these three places, and reports that, 1*st*, In the middle or most direct line, that is, following the rivers Sass and Fiffin, he found that, from the summit to the lake Ladoga, there was a fall of 897 feet upon 174 Russian versts, and from the summit, in the opposite direction, down the rivers Chocodasha and Mologa, to where the Shaxna joins the Volga, the fall was 562 feet upon 420 versts.

2. In the southern track, by the river Emsta, the lake Ilman, and the river Volchoff, to the Ladoga, the fall was 568 feet upon 550 versts; and from the summit in the other direction, by the rivers Twere and Volga, as far as the mouth of the Shaxna, the fall was 223 feet upon 720 versts. This has been the usual line of navigation.

3. In the northern track, by the river Whitegra, the lake Onega, and river Swire, into the lake Ladoga, the descent was 445 feet upon 278 versts; and from the

summit in the other direction, by the river Kioska, lake Beilo, and river Shaxna, to the Volga, the fall is 110 feet upon 418 versts.

This last, although 102 versts longer than the first-mentioned track, being much the lowest part of the general summit, was recommended to be adopted for a navigation. In point of lockage, it has the advantage of 450 feet of less elevation than the first, and 123 feet less than the second. It has now been rendered passable by means of the Mavie Canal, and will enable a communication to be opened to the northern Dwina.

The direct line, although interrupted by a porterage of 60 miles, is yet the channel of a considerable trade.

We avoid entering upon the numerous projects which have been formed between the Neva and the Volga, being yet only matter of speculation.

The southern track, through Novogorod and the lake Hunen, was opened for navigation in the reign of Peter, by the construction of the canals of Ladoga and Vishnie Voloshok; but it was not rendered complete until 1732, in the reign of the empress Ann.

The Ladoga canal is formed along the southern shore of the lake of that name, to avoid the inconvenience of navigating it. The canal commences at Schlusselburg, and is carried on one level 67½ miles to New Ladegaat, the mouth of the Volkof. There is a regulating lock at each extremity. The breadth of the canal is 70 feet, mean depth of water in summer seven feet, and in spring ten feet. It is supplied by the Volkoff, and eight rivulets. Opposite to New Ladoga a cut was completed in 1801, ten versts in length, to continue the canal navigation to the mouth of the Sass river.

The Volkof, although it has various dangerous rapids, forms the natural navigation from the city of Novogorod and lake Hunen to the lake Ladoga. Above it the line comes from the Msta river through the lake Hunen; but this has lately been improved from the Msta to the Volkof, called the Novogorod canals. The great line comes by the river Msta in a very winding course from Vishnie Voloshok, where there is a canal connecting the Msta with the Twere, a navigable branch of the Volga. The rivers Msta and Twere, near the summit level, have not sufficient water for a constant supply; and it is necessary to pound up the rivers and lakes, for a flash, or artificial flood. This is accomplished by pen sluices, and some short cuts. The course of the Msta, to the lake Hunen, is 234 miles; the Volkof to New Ladoga, 130 miles. The whole voyage from Vishnie Voloshok to Petersburgh, is performed in a month.

The third line of communication, by lake Onega, called the Marie Canal, from the Volga, the river Shaxna, is ascended 350 versts to the lake Belozero. It admits vessels drawing 3 to 3½ feet water. The channel is interrupted by reefs of stones. The passage to the river Kofstha is performed in small vessels with sails, which suit both lake and river. These vessels are from 56 to 91 feet long, 25 to 27 feet in breadth, and carry from 50 to 90 tons. After passing the lake Belozero, the navigation continues by the river Kofscha, 65 versts, to the Junction Canal. This river has only eleven feet fall, and locks have been adopted. Two of these were completed and in use in 1808. From the Kofscha there is an ascent to the summit of 48 feet. The Junction Canal, including its basins, is about nine versts in length; the canal part is 70 feet wide at top water, and 56 at the bottom. Upon this summit, the lake Matkosero was found insufficient for supplying water; but, at the distance of 10 versts, the Great Lake Kofscha was quite adequate, and upon a proper level to supply by means of a feeder. From the Junction Canal to the town of Wittegra, 67 versts, the river has a fall of 198 feet. For 10 versts, its bed is obstructed by stone reefs and cataracts. These have been obviated by side-cuts, locks, and wiers.

From Onega the river Suire is navigated into lake Ladoga, and the chief requisite in this line, is a canal along the side of each of these lakes, as far as the mouth of the river Sass, whence the Ladoga canal would complete the communication to the river Neva and St. Petersburgh.

Having explained the lines of communication between the Baltic sea and the great river Volga, we shall now turn our attention to the second great river of Europe and Russia. The Dnieper is navigable, on its main stream, as high as Smolensko, being above 800 miles, and is only, in all that distance, once interrupted by cataracts; they begin below the mouth of the Somara, and continue about 40 miles. In the spring, when the Russian rivers are high, from the melting of snows, loaded barks can descend the falls; at other times the goods are landed, and transported 40 miles by land to Kitchkase, where they are again put into vessels, which pass down uninterruptedly to Kerson. From this port coasting vessels pass through the Limmat, and over the bar of the Dnieper, to Odessa, which is now the natural port of this river. Operations have been undertaken to obviate the cataracts by locks.

Besides the main channel, there are extensive navigable branches: the Prypec is navigable to Pinsk and Alexandria, near Bolbinsk; at Pinsk is the canal already described, which connects with the Niemen. On the eastern side the Deisna is navigable to Bansk, where canals have been projected to the Orel and the Volga. The Lotscho adds 200 miles of navigation, and the Beresina is navigable above Borisof; and, by means of a canal, has been connected with the Dwina and Port of Riga: this is named the Beresinsky canal. It was begun in 1797, and opened in 1805; enters the river Lergin, and proceeds by a side cut, with locks, four miles; then along the stream, for 12 miles, to the lake Planen. From thence is the junction canal, of six miles, with four locks, to the lake Beretscha, below which a side cut, of 1½ mile, with two locks, leads into the Essa, which is followed to the Ulla and the Dwina.

The Dwina affords a navigation from Riga for 600 versts to Toropetz, near which is Volak, on a navigable river falling into the lake Hunen.

The northern Dwina affords a navigation from Archangel, on the White Sea, to Vologda, near which it might communicate with the Shaxna, and, of course, with the Neva and the Volga. Eastward its branches carry the navigation to near the Ural Mountains. These rivers afford floatation to the raw produce of these extensive regions.

In this way. Russia also enjoys a navigation through all Siberia, by means of the great rivers Oby. Irtish, Jenisa, and Lena. In winter, these rivers likewise afford the most convenient roads, even to the frontiers of China.

The only artificial navigation left us to consider, is the connection between the Volga and the Don. The latter is, indeed, only an imperfect navigation. Near

Tcherkask it separates into two streams, which fall into the Sea of Azof, and, excepting in the spring, upon the melting of snows, it is scarcely navigable; and its mouth is also choaked with sand, so that only flat-bottomed vessels can pass. The navigation seems chiefly confined to the main river, which extends about 1000 versts to Epiphany, near its head. From this a canal has been carried towards Zula, on a branch of the Volga, thereby opening an extensive market for the coal and iron of that district.

The canal of Ivan was begun by Peter. It was carried from Epiphany, along the bed of the Don, which in some places is improved by side cuts and locks, as far as the bend of that river, 15 miles above the town. From thence a continued canal passes nine miles across the summit to the Chatch river, having four or five locks on each side of the small lake Ivan, which forms the Summit Pond. The Chatch is also improved by side cuts and locks, as far as Jula on the Una, by which the navigation is subsequently continued to the Oka and Volga.

The grand connection between the Don and the Volga, where they approach each other in the province of Astracan, was one of the earliest projects of Peter the Great. But, above a century before his time, viz. in 1568, it had been attempted by Selim II. Emperor of the Turks, (See Cantemir's *History of the Ottoman Empire,*) but, from various causes, was abandoned, and (as has already been stated) the success under Peter was not much greater, nor yet under the Empress Catherine, when the project was resumed in 1771. As it is unnecessary to enter into details respecting it, we shall only observe, that the river Kamishinka was to have been improved, for 15 miles, by side-cuts and locks; then a canal of three miles, on the summit, led into the Howla, which is navigable into the Don.

Sweden.

This great northern peninsula is singularly interesting, and in no respect more so than in what regards its inland navigation. At what period, or in what manner, it was first peopled, seems beyond the reach of authentic records; but it is well known, that in very remote times there issued from it an energetic race, who, during many ages, triumphed, and formed settlements in various parts of Europe. By the aid of Count Platen, a nobleman to whose talents and assiduity that country stands indebted for many improvements, we are chiefly enabled to furnish our readers with the following observations respecting the inland navigation of Sweden.

Its coast is bordered by innumerable islands and bays, and the whole of the interior is intersected by lakes of various sizes. These lakes are fed, connected, and discharged by large rivers: thus separated, the inhabitants were under the necessity of having recourse, very early, to internal navigation upon the lakes and rivers, although the latter are not unfrequently intercepted by dangerous rapids; and the modes of passing these rapids, in some parts of Sweden, Norway, and Finland, would appear incredible, if they were not still practised. The following detailed account of this operation, as given by the Count Platen, cannot fail to be interesting. Very light and tender boats, of from 20 to 24 feet in length, containing from three to five men, run down the middle of the stream with incredible velocity. It produces a sensation impossible to be described, when, from a steep rock on the shore, one sees the boat approaching the cataract, two men pulling in the usual way with oars, and the pilot, who is appointed and sworn for this business, steering at the helm also with an oar. He particularly is not to be disturbed by any thing whatever: his look is steady and penetrating, and even his hair, on both sides his head, is tied fast behind his neck, lest it might, by the motion of the wind, or by his rushing through the air, wave before his eyes. The moment he reaches the edge of the fall, he animates his companions to pull with all their strength, in order to give his boat sufficient way for the action of the steerage; he then rushes down the tremendous current, between steep rugged shores and isolated masses of rocks, in the midst of the falls, and is frequently hid from the spectator by the foaming of the broken roaring water; in a moment he reappears running with incredible velocity right against a perpendicular rock, with all the probability of instant destruction, increased by his cries to augment the velocity by fresh efforts; when, in the very last moment, as the boat seems touching the rock, he casts it in a quite different direction, often at an angle of 90 degrees, and again disappears in the next curve of the stream. The whole of these operations is an affair of an instant, scarcely to be measured by time. The Count once made a trial of this mode of navigation in company with two able English officers, upon a considerable river in Norway; and though the falls were of the lowest sort, they all agreed that they should not have liked to have trusted the best of their own bargemen. But in rivers of this sort, many rapids defy navigation, and in these cases carrying places are necessarily adopted. The improvement of side-cuts succeeded the carrying places, and some of the latter (or cuts) are so ancient in this country, that their origin is unknown. The old laws and regulations for canal cutting are found as far back as the 14th century. In the year 1007, the neck of land upon which Stockholm stands was in one night cut through by the King of Norway, Olof Haroldson, who, being blocked up in the lake Maelar, escaped by this expedient with his fleet. The navigation from Upsala to Bishop Tuna in 1030, the order issued about the year 1320, by Knut Jonson Blae, in the name of the Swedish King Magnus, for removing the obstructions in the navigation from Upsala to Bishop Tuna, are all testimonies of the ancient existence of inland navigation in Sweden. An ancient author relates, that, in 1435, the administrator Engelbrecht endeavoured to cut through the neck of land at Sodertelje, in order to pass his vessels into the lake Maelaren; and, on the 3d May, 1455, King Charles VIII. directed the navigation from Upsala to Bishop Tuna, to be cleared out and restored. There is in existence a letter from the learned and active Catholic Bishop Brask, to a nobleman of high rank, dated 15th July, 1526, wherein he mentions a plan of joining the Wenern with the Baltic, nearly in the same way as it is now about to be accomplished; and a short cut at the eastern extremity of the lake Roxen, is still known by the name of the Bishop's Canal. But this great man, violently opposing the Reformation in religion introduced by Gustavus the First, was expelled from the country, and all his projects of improvement were suspended.

It does not appear that Gustavus I. took any decided measures respecting a navigation across the kingdom, although it was mentioned by him at the diet on the 28th July, 1526: but his scheme was to join the lakes

Maelar, Hielmar, Sbager, and Wenern; and some ascribe to him the commencement of the Arboga canal. An order of his exists, dated 1546, for deepening the ports of Tonkoping and Wadstena, both on the great lake Wettern. In 1561, he cleared out the navigation from Upsala to the Baltic, at Bishop Tuna.

Eric XIV. had the navigation through Sweden in view, in order to avoid the vexations of the Danes and the monopoly of the Hanseatic towns, but he adopted no practical measures.

His brother John III. in 1581, issued letters for the construction of canals near Troelhatta; and in 1585, for clearing away the woods between the lakes Boren and Asplangen, in order to effect the canal between the lake Wettern and Soderkoping, then a great trading town.

The able and enlightened son of Gustavus I. founded the towns of Carlstad and Mariestad upon the Wenern, and, at the commencement of the river Gotha, which forms the outlet from that great lake, he caused a canal to be constructed which bears his name. About this time lived Duke John of Ostrogothia, who, having travelled in foreign countries, formed the project for joining the Wenern with the Baltic; for which purpose he employed a Dutch engineer. He died in 1618.

In the year 1631, Gustavus Adolphus, amidst his German conquests, issued an order to construct an artificial canal between the lakes Maelar and Hielmar; and the following extract, from an authentic document, proves his anxiety and zeal for its execution. It is entitled, "An extract of the declaration of King Gustavus Adolphus, on the questions put by Count Palatin, John Cassimir, and Council of the Chambers, dated the Field Camp at Passewitz, near Wittenberg, 31st August, 1631:"—"Though his Majesty distinctly perceives that the parishes in Nerica, which are allotted to dig the Hielmar canal, only endeavour to gain time and ulterior exemption from conscriptions, and are not working in earnest, and is thereby tempted not to grant them further exemption, yet his Majesty will make a trial of their diligence for another year, and grants them the same exception for that time. His princely Grace Count Palatin may therefore please, with the Council of Chamber, to see that the peasants work with application, and that Charles Bond looks at it as due. For the rest, as lock building demands stability, so that it may last not only for the present time but for posterity, his Majesty desires that his princely Highness Count Palatin and Council of Chamber will have it constructed of stone, and not of timber, though it should cost a thousand dollars, or somewhat more. For the rest, if the lock builder, now there, has not such knowledge thereof as he ought, it seems better to his Majesty to write for one or two from Holland to look at it, whom his Majesty will rather pay their travelling expenses, and something for their trouble, so that the work may become lasting, and posterity reap the benefit and use of it; and in the ground where the locks are to be constructed, are rock and stone, his Majesty thinks it unnecessary to make the bottom of planks, but endeavour to make it from the very foundation all along, so that it may be more lasting and firm, and unnecessary expense avoided."

In 1632, the Arboga canal between the Maelar and Hielmar was constructed (during the minority of Queen Christina) with 12 locks.

In the year 1635, orders were given to a Swedish engineer, of the name of Traesk, to examine the summit of the country, which has lately been adopted for the Gotha canal; and, in 1640, a Dutch ambassador pointed out its importance, and at this time the cut and lock at Edit, upon the river Gotha, were made. There were also various surveys made to avoid the Trolhatta Falls; and during the reign of Charles X. the town of Gothenburgh and its excellent harbour, and the mouth of the great river Gotha, were rendered more secure.

Charles XI. in 1691, began to reconstruct the Arboga canal in a more substantial manner. The chief engineer was a Dutchman, who unfortunately still continued to employ the river channel, although the adjacent ground is particularly favourable for an artificial canal. The navigation is, from this circumstance, subject to flood waters and sediments. The king employed the soldiers, and having encamped on the adjacent ground, he himself inspected and directed the practical operations. It was completed by his son in 1701. The distance between the Maelar and Hielmar lakes is eight miles, and the fall $79\frac{3}{4}$ feet. The number of locks is now eight.

Charles XII. employed the engineer Polheim to plan a navigation across the kingdom, upon the line pointed out by Bishop Brask, viz. through the lakes Wenern, Wiken, Wettern, Boren, and Roxen, and to the town of Norkoping, which had now supplanted the more direct line to Soderkoping; and the excellent channel from the Baltic up to the latter was interrupted by a clumsy wooden bridge. The plans of Polheim are still preserved; he was of a bold and enterprising character, probably influenced, in some measure, by that of the sovereign under whom he acted; and the celebrated falls of Trolhatta, in the great river Gotha, furnished a fit subject for such minds. To connect the navigation from the river Gotha with the lake Wenern, Polheim formed the design of damming up these falls, by building walls across the rapid torrents of Trolhatta, and constructing three locks, having altogether a rise of 114 feet. A contract was absolutely entered into between the king and the engineer, not only for this, but the whole navigation across the country to the Baltic; but the death of this brave and extravagant monarch suspended the project. In 1746, the Trolhatta scheme was approved of, and Polheim, though old, was consulted by the resident engineers. In 1755, three locks were excavated in the rocks, along one side of the falls, and gates of a particular construction were placed in the uppermost. One arm of the stream, in the uppermost fall, was dammed up, which yet remains. A great dam across the whole river, beneath the last fall, was nearly completed, when it was wholly carried away by the force of the stream on the 20th September 1755. About 900 dozen of planks had, the preceding day, been thrown into the river, for what purpose has not been ascertained; but having accumulated in a mass against the unfinished dam, proved the immediate cause of its destruction. This left the impression of impracticability on the minds of the country; and excepting the construction of a bad lock at Carlsgraff, all remained in a dispirited state until 1772.

Meanwhile the Arboga canal having fallen into a state of decay, in the year 1768, the town of Orebro, being much interested in this communication with Stockholm, offered to reconstruct the works, to which the crown agreed, and the whole was given up to the town.

In 1767, instructions were given to M. Thomberg, (who, in 1757, had given a plan for Trolhatta, nearly the same as the one executed,) for a new survey between the lake Wettern and the Baltic; and similar instructions were given to Captain Rook, who reported that the line by Soderkoping was by much the best, and recommended that the project should be undertaken by a private company. In 1774, M. Thomberg's opinion was again taken up by the king respecting the whole navigation across the kingdom; and a lock and side cut were constructed on the river Gotha, by the side of the cataract of Akerstrom, which, with the lock at Edit, perfected the navigation from Gothenburg to the Trolhatta falls. As these were 114 feet ascent upon 8000 feet in length, a wooden railway was constructed; and the locks at Karlsgraff were, in 1778, reconstructed in a more perfect manner. In 1781, 1782, 1783, and 1784, M. Thomberg was employed in his surveys across the kingdom, and he was of opinion that Soderkoping was the best termination; however no practical measures were then adopted.

In 1765, plans were produced for an inland navigation from the province of Daleme to the Maelar, called the Stromsholm Canal, which had been proposed in 1757. This was undertaken by individual subscription, with some aid from the crown. The work was commenced in 1777, and completed in 1795. The whole length is about 60 English miles; the fall 336 feet; the number of locks 25. The length of some are 80, of others 66 feet; their breadth is 18 feet; and the canal has 4½ feet of water. This is a very imperfect navigation, being a mixture of natural water courses. The chief articles transported are pig and bar iron, to the amount of 4000 English tons annually.

Another communication, most of which remains to be performed, is to connect the lakes in the province of Ostrogotha, between the towns of Linkoping and Wimmerby, under the name of the Kindæ Canal. It was proposed in 1756, probably by the famous Colonel Pechlin, who, at his own expense, made several cuts, and took other measures respecting it.

Thus we find, for the space of three centuries, the canal business a constant object of public attention, and frequently treated with great earnestness, but still with very little effect. It must therefore be inferred, that there is a certain degree of civilization, public wealth, and trade, necessary to support such improvements. Previous to this they are merely possible, when the means, capacity, and desire, happen to be united in a sovereign or a state, when they may be forced prematurely, as in the case of Charles XI. the Czar Peter, Frederic of Prussia, and Louis XII. But, besides the before-mentioned general difficulties, there are others peculiar to Sweden. The numerous large lakes render it imprudent to think of employing vessels, or connecting canals of small dimensions, and, consequently, in the very first essays great means are required. Sweden may be supposed to have reached the period at which inland navigation might be attempted with advantage, when, on the decease of Gustavus III. the regency of the kingdom was entrusted to his brother the late king. The want of an uninterrupted navigation was strongly felt, and a plan for passing Trolhatta was laid before the king by a company of subscribers, in 1793. It consisted of a cut from a small bay immediately above the falls, along a rocky bank, to a precipice, where it was to descend by nine locks, mostly excavated out of the solid rock, after which it entered the river at a considerable distance below the falls, where the water was placid. In order to encourage the project, the locks which had been constructed at Edit and Akerstrom, several pieces of land, and a certain quantity of gunpowder, were granted by the crown to the company, on condition that they executed the canal to the breadth of 22 feet, with a depth of 6½ feet of water, in the course of six years. The tolls for the whole navigation were fixed at 3s. 3d. English per ton for iron, as the chief article of export. Other articles paid in proportion. The subscription, amounting to 765,000 rix dollars, was filled up. M. Nordwall was appointed chief engineer; and the canal and locks were completed in the month of August 1800. The whole navigation between the town of Gothenburg and the lake Wenern is now the property of the company; and the revenue amounts to 9 per cent. upon their capital expended, which was only about 55 per cent. of the sum subscribed.

The success of this project caused the revival of a scheme for opening a passage through the narrow neck at Soderteljo, to unite the lake Maelar with the Baltic; which was actually undertaken by subscription. The privilege issued in 1806, stipulating a breadth of 30 feet, with 12 feet depth of water. This, though short, being in very deep cutting, has proved an arduous undertaking, and was only completed in 1819.

The complete success of the Trolhatta canal was also the means of reviving the great object of opening a communication from the Wenern to the Baltic at Soderkoping. The improving state of the nation also had, no doubt, very considerable influence: but the merit of its having been brought forward, adopted, and the advances procured for carrying it into effect, is chiefly to be attributed to the same nobleman, to whom we acknowledge ourselves indebted for the information respecting Sweden, and to whose enlightened and patriotic views, great talents, and unwearied perseverance, that country owes much.

The Count Platen, then in the sea service, having in the year 1795 seen the works at Trolhatta, was strongly impressed with the advantages to be derived to the country by extending the navigation across the kingdom, and thereby rendering the trade of Sweden independent of the Sound. Upon his afterwards retiring from the service to his estate near Trolhatta, in the year 1798, he was elected into the direction of the works at that place. This, in a short time rendered him familiar with canal operations. He next made various journeys through the country; and found out the plans of the deceased Thomberg. From these, together with his own observations, and the conversations of his friends, more especially an enlightened physician, the Count became so fully persuaded of the practicability and utility of the project, that, in 1806, he published a pamphlet, recommending the plan of Thomberg. Early in 1808 he had a long interview with the king on the subject, when the business was so far approved of and arranged, as to produce an order authorizing the Count to procure an accurate resurvey by a British engineer of known experience in similar works. Mr. Thomas Telford, then conducting the great Caledonian Canal through large lakes in Scotland, and the Ellesmere Canal, (on which there were some uncommonly large aqueducts,) in England, was selected for this purpose. The Count lost no time in making the application; and Mr. Telford having acceded to it, he and his assistants, through the friendly offices of Sir James Saumarez, then commanding a British fleet on the Swedish coast, were landed at Gotenburgh early in August, 1808. He immediately commenced operations;

and from the zeal and masterly arrangements of Count Platen, he, with unprecedented expedition, carried a regular survey from the eastern shore of the lake Wenern, to the shores of the Baltic at Soderkoping. He found the maps and surveys of Thomberg perfectly accurate; and the chief points in which he differed from that engineer, were either in respect to the site of locks, or to avoid deep cutting, or river navigations. The lakes, soil, and materials, were all found to be very favourable; and having completed regular plans, sections, and a detailed report, Mr. Telford, with his assistants, embarked for England early in October, leaving this magnificent project in the hands of its zealous promoter Count Platen.

In 1809 the revolution took place, and at the ensuing diet the Count laid the plans, &c. before the king and the diet, when the project received unanimous approbation. It was to be executed by a subscription company; and a charter to that effect was signed by his majesty, 11th April, 1810. The locks were to be 24 feet in breadth, the canal bottom 48 feet, and, when the slopes will stand, at an angle of 30°. There is to be 10 feet depth of water. The length of the whole navigation from the Wenern to the Baltic, including lakes, is 18 Swedish, which is equal to about 120 English miles. The artificial canals make 8¼ Swedish, or about 55 English miles. The ascent from the Wenern to the summit, or surface of the Wiken lake, is 162 feet: the fall to the Baltic 307 feet. The number of locks is to be 56.

The subscription was opened in May, 1810. At the first meeting the Count Platen was appointed chairman, and manager in chief, and this appointment was confirmed by the king. In 1810, 1000 workmen were employed; in 1811, 5000; in 1812, 6300; and in the beginning of 1813, upwards of 7000; but the war operations reduced them to 3000. In August of this year Mr. Telford visited and inspected all the works, which had hitherto consisted chiefly of cutting, and had been very correctly performed. The sites of the locks, bridges, and aqueducts, were now precisely determined, and all the principal matters arranged; and under the sanction of the British government, experienced lock builders and earth workers were sent over by Mr. Telford, with the necessary plans and implements. The works have ever since been carried on with increasing assiduity, and many of the most difficult and expensive locks have been completed. A considerable portion of the canal has been rendered navigable, and its importance has become apparent; so that Count Platen will deservedly enjoy the same consideration in his country, as the late Duke of Bridgewater, for similar laudable exertions, enjoyed in our own.

England.

Having taken a cursory view of the progress and present state of Inland Navigation among the various nations of the Continent, we shall now proceed succinctly to show what has been done in the British isles. To do this part of the subject justice would require volumes; and although we shall endeavour to treat it with the utmost brevity, its extent will unavoidably prove very considerable.

Although we have a vast extent of sea coast and navigable inlets, and also several very considerable rivers, yet the works of artificial navigation among us are only of a comparatively late date. Notwithstanding this, their number and extent are now so great, and their ramifications so general, that, south of the river Tees, no part of England is 15 miles distant from navigation; and so far from these improvements being, as in other countries, the work of princes, or their ministers, our legislators have not unfrequently interfered to obstruct the energies of individual exertion.

Until the invention of locks little could be done in the way of inland navigation in England, except in the Fens, when connected with drainage. Two works however yet exist in that neighbourhood, of unknown antiquity, and probably Roman, certainly intended for navigation: 1st, The Car Dyke or Fossa Caravansii, (as it is termed by Stukely,) a canal 40 miles in length, skirting the uplands and fens from the river Nen at Peterboro', to the river Witham near Lincoln; and, 2dly, The Foss Dyke which connects the Witham at Lincoln with the Trent, above Gainsboro', by a level cut of 11 miles. The first of these works is now in disorder; but the second was, as we are informed by Cambden, cleaned out by Henry I. and is now an existing navigation, the oldest perhaps in England. By means of these two works, and the rivers Nen, Trent, and Ouse, an actual navigation of great extent was effected. It is probable that the Foss river at York was, besides drainage, intended for an extension of this navigation; though possibly, with the incumbrance of occasional transhipment; and this, when the country was without roads, and otherwise inaccessible, was a most valuable accommodation.

In subsequent times, the free navigation of our great rivers seems frequently to have attracted the attention of the legislature. Magna Charta, cap. xvi. provides, "That all Wears shall be put down on the Thames and Medway, and through all England, except on the coast;" 25th Edward III. 1350. There is an act that new wears shall be pulled down, and not repaired; of which the preamble shows the natural navigation of rivers to be the object of attention: "Item, Whereas the common passage of boats and ships in the great rivers in England be often times annoyed by the inhancing of gorees, mills, wears, stanks, stakes, and kiddles, in great damage of the people, it is accorded and established, that all such, &c. shall be utterly pulled down, without being renewed." This act was confirmed by 45th Edward III. with a penalty; also 21st Richard II. c. 19.; 1st Henry IV. c. 12; 1st Henry V. c. 2; 4th Henry V. c. 2; 9th Henry VI. c. 9. Enforced by 12th Edward IV. c. 7. which inflicts a penalty. See farther 3d John I. c. 12; 7th John I. c. 19. 6th and 7th William III. c. 16; 1st George I. st. 2. c. 18. Commissioners of Sewers were also appointed: They were instructed to attend not only to Drainage but Navigation, viz. "the removing and preventing impediments and annoyances on rivers, streams, and floods, whereby the passages of ships and boats might be letted or interrupted." In 23d Henry VIII. c. 5. a general act was passed, specifying the form of commission, as in 6th Henry VI. c. 6, and otherwise regulating their powers, which are very extensive.

By sundry acts, viz. 9th Henry VI. c. 5; 19th Henry VIII. c. 12. were passed, which declared the river Severn a free navigation; this was in consequence of some local claims having been set up, and tolls demanded. By the 2d Henry VI. c. 9. an act authorizes the justices to inquire into and remove nuisances on the Thames. By the 3d Henry VI. c. 5. commissions are directed to be issued by the chancellor to fit and skilful persons, at all times necessary, in order to amend all faults in the river Lea. 9th Henry VI. confirms the same, authorizes the removal of shoals, and grants a toll of 4d. per boat for three years, in order to defray the expense. This is the first instance we have found of a toll being granted for the purpose of improving river navigation; and this contemplated only scouring and deepening the river, and removing artificial obstructions. The word Lokkes is first mentioned in 12th Edward IV. c. 7. as an obstruction in navigable rivers, but cannot be supposed to mean any contrivance for facilitating the passage of vessels, &c. It is doubtful if the canal lock had been then invented; and the same word lokkes is still used for the locks of London bridge.

The 6th Henry VIII. c. 17. is an act to make the river of Canterbury navigable, by deepening and embanking. By 27th Henry VIII. c. 18. the conservation of the Thames is granted to the mayor and corporation of London. In 1539, 31st Henry VIII. c. 4. power to make a distant cut is given to the mayor and corporation of Exeter. The object of this act was to restore to the city of Exeter the navigation which had been destroyed by Hugh Courtney, Earl of Devon. This new cut was not provided with sluices until 1581; and it was not until a century afterwards, viz. in 1675 and 1697, that the corporation were enabled, by the introduction of locks, to complete a navigation to the city for vessels of 100 tons. In the 13th of Elizabeth, an act passed to make the Welland navigable. The works then executed still exist, and are of the rudest sort. In 1571, an act was passed for an artificial canal, to bring the river Lea to the north side of the city of London; but it was not acted on. The new river aqueduct was a specific act obtained under James I.

The reigns of the Stuart family, therefore, must be assumed as the era of the actual commencement of artificial inland navigation. James I. sent engineers to view the Fens, and suggest means for their relief; and agreed that the crown lands should contribute towards the expense. In the 21st James I. c. 42. an act was passed for the navigation between London and Oxford, which may be said to be the parent of the river acts. In 1610 the river Lea bill was acted on, and brought to Limehouse.

In 1655, an act was passed to make the river Wye navigable; and in the same year for the Ouse, from the Humber to York.

It is evident from their repeated failures in the Fens, that the artists then in England were deficient in experience and skill. James, therefore sent for engineers from Holland, which country was then busy with various works of drainage and navigation, and at that time supplied all Europe with hydraulic engineers. (See LALANDE, pp. 175, 195, 197.) So early as the reign of Henry VIII. Cornelius Vanderdelp embanked and drained the marshes of Wapping, and had one half the land for his trouble, confirmed by repeated acts of parliament. On the same principle Cornelius Vermuyden undertook, in the reign of James I. to embank Dagenham levels on the Thames; and a part of the lands was confirmed to him by patent in 1621.

Vermuyden and other Dutch artists were sent to drain the eastern and northern fens; and in 1626, under Charles I. they made proposals for recovering the great level, and that of Hatfield Chase, at the mouth of the Trent. This last was effected in five years, at an expence of £55,825. They also built Misterton Sas, in the river Idle; probably the first lock with a chamber which was built in England. It was rebuilt by John Smeaton. Although these Dutchmen were frustrated as to the great level, and also the Aire and Calder rivers, their example communicated intelligence and skill to Englishmen, and promoted similar improvements. But, unless when connected with drainage, navigation does not seem to have been made an object of attention. If we may rely upon the representations of the town of Lynn, it was very materially obstructed. Indeed, until the act of 1661 for the Bedford canal, no provision was made respecting the navigation.

In 1628 a bill was brought in to improve the river Medway. It was not then passed, but the improvement was subsequently undertaken by Michael Cole, under a royal patent. Having, however, been petitioned against under the commonwealth, it was set aside as a monopoly. During the troubles and civil wars no progress was made in these sort of works; indeed, many of those previously constructed were injured and destroyed.

After the Restoration, inland navigation was taken up with zeal. Charles II. and many of his courtiers, during their exile in the Low Countries, had opportunities of witnessing the benefits of inland navigation; and it is worthy of notice, that all the bills originated with the lords. In 1661 and 1662, unsuccessful attempts were made to obtain a general law for making all rivers navigable which were capable of it. Private bills were however passed.

Acts were passed for the rivers Stour and Salwerp, in the counties of Worcester and Stafford, Wye and Lugg, in Hereford, Monmouth, &c. This last act was subsequently amended by a public act, 7th William III. which gives authority to assess the county of Hereford for the expense.

Acts were also passed for the river Avon, from Christchurch to New Sarum; also the river Medway, &c.; the Mole and Arun, from London to Dorking, Grimstead, Arundel and Petersfield; likewise by the Wey to Farnham, and the Itching from Southampton to Winchester; and soon after for the rivers Branden and Waveney, the Witham, &c. from Boston to the Trent; and an act for the conservation of the Fale, near Falmouth. In the 6th and 7th William III. the Justices were authorized to settle the rates for the locks and weirs upon the river Thames. In the 9th and 10th William III. the corporation of Colchester was authorized to make their river navigable to Wivenhoe. In the following session, 10th and 11th William III. the Aire and Calder act passed. This may be considered as the parent of the Yorkshire navigations, and is now, perhaps, the wealthiest in England. In the same year was passed the Tone, from Bridgewater to Taunton, and for the Trent in the counties of Leicester, Derby, and Stafford. Next year, for the Larke or Bame, near Bury St. Edmond; for the Avon and Fronme, above Bristol; and for the river Dee.

We have now arrived at the commencement of the last century, so very important in the history of the Inland Navigation of England; and it appears from the preceding rapid sketch, that so far from our nation being neglectful of this part of domestic improvement, as alleged by Lalande, the progress which had been made, considering the then confined state of our trade and capital, and the turbulent period of our political history, was not inferior to that of most of the other nations of Europe.

Under the succeeding monarchs, the extension of our inland navigation was pursued with accelerated rapidity. From 1701 to 1714 the following canal acts were passed —for rendering navigable the Avon, from Bath to Han-ham Mills; the Cam, or Grant, from Claybithe; the Derwent, in Yorkshire; Nene to Northampton and Peterborough; Stour in Essex from Mannington to Sudbury, Suffolk; and for the river Tone.

From 1714 to 1727, in the reign of George I. acts were obtained for improving and extending the navigation of

Beverley Beck at Hull.
Dane in Cheshire, from Northwich to Wheelock Brook.
Derwent in Derbyshire.
Dee, Cheshire.
Douglas, from Ribble to Wigan.
Don in Yorkshire, from Doncaster to Tinsley.
Do from Holm Stile to Wilnich House.
Eden to Bank-end.
Idle River.
Irwell River.
Kennet to Newbury in Berks.
Lugg.
Mersey to Manchester.
Nene to Northampton.
Ouse to Huntingdon.
Ouse to York.
Thames to Cricklade,
Weaver in Cheshire, from Frodsham to Winsford.
Wey in Surrey to Godalming.
Wye in Hereford.

And under George II. or from 1727 to 1760, acts were passed for improving.

Beverley Beek near Hull.
Blythe in Suffolk to Haldworth Bridge.
Branden River.
Ivel or Yeo in Somersetshire.
Loyne or Lune.
Medway.
Lar, from Lynn to Westaire.
From Old Bedford Sluice to Nene.
Rodon in Essex.
Sankey Brook and branches.
Stort.
Stroudwater.
Waveney.
Weaver.
Worseley Brook, from Worseley Mill to Irwell.

At the commencement of the reign of George III. the system of inland navigation in England underwent a very remarkable change. Hitherto acts of Parliament had been granted with reference to some particular river, the natural navigation of which it was meant to improve. Powers were therefore granted to deepen and straighten the channel, to embank where it was too wide, to employ such banks as towing paths, to build jetties and weirs, to pen up water by sluices or turnpikes, or to make flashes to overcome the shallows or rapids; to erect winches or capstans for hauling boats up the rapids, &c.; and latterly, to build pound locks for overcoming the ascents, especially at mill weirs: but it was usually stipulated not to leave the bed, or direct the river from the natural course, or draw water from it to the injury of the mills. Experience had, however, shown that navigations of this sort were liable to perpetual degradation. The rivers which had their regimen altered, were found speedily to change the form of their beds. Gravel and sand were swept away by the rapids at the weirs, and deposited in banks and shoals in the ponds below. During floods the works were overtopped by the water, and frequently injured; and the crooked navigation, with its trackage against the stream, was at all times laborious and dilatory. These difficulties suggested the propriety of leaving the natural bed, and led to the formation of a separate cut with pound locks. With this view the proprietors of the Sankey navigation, in Lancashire, who had obtained in 1755 an act for making Sankey brook navigable from the Mersey river to near St. Helen's, having the usual powers given them for purchasing the necessary land for side-cuts, &c. determined, instead of working in the river, to make a separate cut along the same, which they accordingly effected in 1760, supplying the head or upper level only by a feeder from the stream.

About the same time the Duke of Bridgewater, who had obtained an act for making Worseley brook navigable, from Worseley mill to the river Irwell, by which navigable river he proposed to transport the coals from his property to the manufacturing town of Manchester, duly appreciating the superior benefits of a still-water navigation, conceived the idea of conveying an artificial canal through the dry land, across the river Irwell, by an aqueduct, and thereby proceeding from the mines, upon one level, to the town. In the 33d George II. the Duke obtained the first act, with adequate powers for the construction of a canal of this sort, that is, not in the direction of any stream, but crossing the course of rivers, brooks, and roads, and intersecting the property of various individuals, who were to be fully compensated, though prevented from obstructing the design. The scheme at first met with much discredit, from the prejudice which then existed in favour of river navigation, and on account of the unprecedented expense and difficulty of constructing these necessary aqueducts, embankments, and other works at that time new in England. But the Duke, who was well acquainted with what had been performed in Holland, France, and Italy, and having found an able and ingenious practical assistant in Mr. James Brindley, and likewise a singularly sagacious and persevering agent in Mr. Gilbert, was not deterred from effecting his bold designs. The signal success of the Duke's projects opened the eyes of the whole nation to the vast advantages to be derived from artificial canals, or rather stillwater navigation. Its extensions from the Mersey to the Trent, Severn, and Thames, were successively projected. These, and the rapid formation of joint-stock companies, of which above 100 have been incorporated for works of this sort, during the last reign, are evidence of the zeal with which these improvements were prosecuted. An incredible extent of these artificial canals has now been completed, that is to say, upwards of 2400 miles have been made in England, constituting a congeries of inland navigation not to be equalled in the world, and in the construction of which all sorts of difficulties have been experienced, and overcome by the talents and perseverance of an ingenious and industrious nation.

In proceeding with the detail of the several navigations of England, we conceive it will be most advisable for our readers to have the whole arranged into districts, referring to the grand outlets and natural navigation of the kingdom. We therefore propose to treat of them in the following order.

1. The basin of the river Thames, including the various navigations to the south of it, and along the channel to the extremity of Cornwall.

2. The estuary and vale of the Severn, and its connections with the Thames; also including Wales, and as far as the island of Anglesea.

3. The Mersey, or Bay of Liverpool, and the connecting canals from thence towards the Humber.

4. The Humber estuary, with the Trent, Ouse, and other branches, also including the remaining river navigation on the east coast.

5. The washes and basin of the Fen district, between the Thames and the Trent, with some account of the drainage there.

6 And lastly, The grand central canals of junction which unite the Thames and the Mersey, the Trent and the Severn.

The great thoroughfares, or canals of junction, will unavoidably fall to two or more districts; but we shall endeavour to render this as little inconvenient as possible.

1. *The Thames.*

This noble river, the most important for trade and navigation perhaps in the world, having its estuary near the Dover Straits, the great highway of Europe, has for many ages been the resort of mercantile shipping. London, the capital of the British Empire, with a population of upwards of a million, is situated at the head of its ship navigation, 60 miles from the sea, and accessible by vessels of the greatest burthen. For 37 miles farther, to Staines, barges navigate the open estuary; for 110 miles farther, to Lechlade, the river has been rendered navigable by locks and weirs, and various canals communicate with it in numerous directions.

The Thames runs in a basin of chalk; no mines are found within its limits. The great article of coal is therefore an article of transport. However, chalk, flint, firestone, building stone, and fuller's earth, with the agricultural produce for the supply of the metropolis, create a considerable water carriage. London, from its singularly advantageous situation, has become the greatest emporium of Europe, especially for colonial produce. The freedom of our constitution, our insular position, maritime power, and consequent security from the vicissitude of war, give it great advantages over its ancient rivals on the Scheldt or Rhine; and therefore, while Bruges, Antwerp, and Amsterdam, &c. have declined, London has rapidly advanced in prosperity, and its trade comprehends every description of commerce known in Europe. London is also a great manufacturing town, and sends from its workshops various articles of necessity or luxury. In 1800 it was stated, that, including repeated voyages, 13,144 ships and vessels were employed in the trade from London to foreign countries, the colonies, and coastwise, besides 2,288 lighters, barges, and punts, used below Bridge; 3,336 of the like vessels above Bridge; 3000 watermen's wherries; 350 boats, being exclusive of ships of war, transports, &c.—making a total of 22,500 vessels employed in the trade within the port of London. The value of goods imported and exported annually by them was upwards of sixty-seven millions Sterling.

Between the isle of Thanet and the coast of Essex, the Thames is 25 miles in width; at Sheerness it is only five miles. Here the Medway enters from the southward; it has spacious and deep havens to Chatham and Rochester. On the north side of the Thames, the rivers Colne, Blackwater, and Crouch, and the Leigh Road, are navigable inlets.

From Sheerness to Gravesend, 45 miles, the channel contracts to half a mile, and by bending its direction, becomes a land-locked harbour. From thence it proceeds, by a winding course, 22 miles to the Pool, where its breadth is reduced to 3 or 400 yards.

An artificial canal has been formed across the Isle of Dogs, of 1¼ mile in length. Within this space it connects with its navigable branch the river Lea at Blackwall and Limehouse, on the south side, at Rotherhithe and Greenland Dock with the Grand Surrey Canal. Extensive wet docks have been constructed at Blackwall for East India ships, in the Isle of Dogs for West Indiamen, and in Wapping for other vessels frequenting the port of London.

The following table, extracted from the second Report respecting the Port of London, shows the state of the tides near that city.

	Rise of Tide.		Time of Rising.		Time of High Water.
	Feet.	In.	H.	M.	
Botolph Wharf . . .	18	10	4	22	II. 26
Tower Wharf . . .	18	1	4	44	II. 23
East Lane	18	1½	4	44	II. 20
Shadwell Dock . . .	18	5½	4	44	II. 14
Limehouse	18	10	4	44	II. 8
Greenland Dock . .	19	2	4	45	I. 58
Deptford Creek . .	19	6½	4	45	I. 54
Crawley Wharf . . .	19	10	4	45	I. 47
A Sluice opposite Lea	20	2½	4	45	I. 40

The greatest depths at low water vary from 15 to 28 feet, in numerous soundings taken from Billingsgate to Blackwall.

Scale of Tides at	Shadwell.		Bugley's Hole.	
	Feet.	In.	Feet.	In.
At High Water . .	18	5½	20	2
Three quarters Flood	16	3	16	3
Half ditto	11	3	12	0
Quarter ditto . . .	5	6	5	9
Low Water . . .	0	0	0	0

By this scale it appears the tide rises considerably higher than half the whole height in half the time of flood.

The stream at Spring tides runs up about 20 minutes after high water at the shore; and in the middle from 30 to 32 minutes.

Above London Bridge the tide flows 18 miles to Richmond; but the authority of the Corporation of London, as conservators, by acts 14 and 17 Geo. III. extends to the City Stone, half a mile above Staines, and 37½ miles from London Bridge by water, though only 16 by land. In this distance there have been considerable improvements attempted by ballasting, and contracting the channel over shoals, and establishing regular flashes of water from the ponds and mill-dams in the upper part of the river. A horse towing-path has also been formed from Putney Bridge upwards. Still it was found necessary, in the 50 Geo. III. to obtain an act for making four pond locks, viz. at Teddington, Sunbury, Stowers Gut, and Laleham, with opening weirs to pen up the water to 3 feet 10 inches. A toll of 4d. per ton for a voyage, was granted for these purposes.

On the north shore at Brentford is the southern termination of the Grand Junction Canal, one branch of which reaches the metropolis at Paddington, and, by the Regent's Canal, communicates by the northern skirts of London with the Thames at Limehouse. This Grand Junction Canal connects London with all the great navigations of the central and northern parts of England. On the south shore of the Thames at Vauxhall, the Grand Surrey Canal is intended to join the Thames; and at Wandsworth entrance is the commencement of the iron railway to Croydon. Near Weybridge, the river Wey navigation passes off to the south, and joins it to the Basingstoke canal, in a south-west direction.

From Staines upwards, past Windsor, Maiden Head, Marlow, Henley, Reading, Abingdon, and Oxford, to Lechlade in Gloucestershire, a distance of 109 miles, the managements are designated by the name of the Thames and Isis navigation, by the 24 Geo. II. and 11, 25, 28, and 35 Geo. III. This has been vested in country gentlemen, by whom it has been improved by means of 27 pond locks, and nearly as many side cuts, by making a horse towing path throughout the whole line of navigation, and lastly, by ballasting various shallows, so that, as Mr. Alnutt, the superintendant, states, 3 feet 10 inches of water is now at all times secured. The size of the locks is, in general, 120 feet long and 18 feet wide. The distance from Staines to Oxford, by this navigation, is 81 miles, by the turnpike road only 42. At Lechlade, the surface of the water is 212 feet above the tideway of the Severn, at the termination of the Stroudwater canal. Between Lechlade and Staines, the following navigations connect with the Thames: 1st, Near Reading, the river Kennet, from which the Kennet and Avon canal proceeds to Bath and the Severn. At Abingdon, the Wilts and Berks canal proceeds westward, unites with the Kennet and Avon, and likewise sends a branch (the North Wilts canal) to rejoin the Thames near Lechlade. At Oxford, the Oxford canal passes northward, and unites with the canals of the central district. While, at Lechlade, the Thames and Severn canal passes westward, crosses the central ridge of the island by the Sapperton tunnel of 4300 yards in length, and descends into the Stroud canal, which falls into the river Severn.

The tolls are 3d. per ton per voyage for each pond lock, or 6s. 9d. for the whole between Staines and Lechlade, besides a small toll of 2s. per ton for the whole length, for weir owners. The following table from Mr. Alnutt's pamphlet deserves notice.

Prices of Carriage of Goods per Ton from London.

	By Water.	By Land.
To Windsor, or Maidenhead	£0 9	£1 10
Marlow or Henley . . .	0 12	2 5
Reading or Caversham . .	0 15	2 10
Wallingford or Bensington . .	0 18	2 18
Abington or Oxford . . .	1 2	3 5
Farringdon or Lechlade . .	1 8	4 0

Branches of the Thames.

Reserving the three great junction canals, we shall proceed to those navigable branches of canals or rivers which are connected with the Thames.

The side cuts and pond locks up the river Wey, in Surrey, between Guildford and the Thames, are said to have been amongst the first in England, and constructed by Sir Richard Weston, in 1651. In this distance, there is a rise of 86½ feet in 17½ miles, and from thence to Godalming, 2¼ miles, a canal rises 32½ feet. The vessels employed are 70 feet long and 12 feet wide, and 3 deep, and carry 45 tons. The imports are, coals, fir timber, bale goods, tallow, and groceries. The exports are, chalk, oak timber bark, hoops, paper, malt, flour.

From the Wey, at two miles from the Thames, the Basingstoke canal commences, and proceeds westerly 37 miles, in the counties of Surrey and Hants, to the town of Basingstoke, in the first 15 miles, 29 locks ascend 195 feet, the remaining 22 miles are level. Acts 18 and 33 Geo. III.

In Berkshire, the river Kennet was made navigable by side cuts and pond locks, in the early part of the last century. From near Reading it ascends 142 feet, by 11 artificial cuts and 20 locks, to Newbury, distant 18 miles. The locks are 122 feet long and 19 wide; barges 109 feet long, 17½ wide, and 3½ feet deep of water, carrying 110 tons. Acts 7 Geo. I. and 3 Geo. II. From Newbury the Kennet and Avon canal proceeds westward to Bath.

Returning to London on the north, the river Lea was made navigable by Acts 12 Geo. II. and 7, 19, and 45 Geo. III. It commences at Blackwall, and proceeds northward, by Waltham Abbey and Ware, to Hertford, 20 miles, with a branch to Bishop Hertford of 13 miles.

At Bromley, a canal proceeds south-west to the Thames at Limehouse, which avoids the peninsula of the Isle of Dogs. The length of this cut is 1½ mile. This was made at the expense of the city of London. The river Lea was originally made navigable by means of weirs and single sluices. In 1767, John Smeaton was consulted respecting this navigation. The early formed locks on this river were without walled chambers. There have been various projects for extending this navigation, to the river Ouse in one direction, and the northern parts of London in another.

It was not until 1808, that any canal, entirely separate and independent of rivers, was constructed adjacent to London. In 1801, acts of Parliament were obtained for three separate projects in the county of Surrey, viz. the grand Surrey canal, the Croydon canal, and the Surrey Iron Railway. The first commences at Wilkinson's gunwharf, in Rotherhithe, and proceeds 12 miles to the town of Mitcham. There is one branch to the dock-yards at Deptford, another at Greenland dock, a third at Bat Lane, a fourth to Peckham, a fifth to Horsemonger Lane, and a sixth from near Walworth, to join the river Thames at Vauxhall. From its commencement for a distance of two miles, to which the Croydon canal branches off from it, it is nearly on a level with high water of the Thames. It also continues on the same level westward to the separation of the Vauxhall branch, and the above mentioned branches are on the same level. The upper part of the mainland has a considerable rise, and it was originally intended to extend it to Epsom and the Wey, as part of a line from London to Portsmouth.

The Croydon canal is a branch of the last. Commencing near Deptford, it proceeds southward 9½ miles to the town of Croydon. In the first 1¼ mile, 12 locks raise it 70 feet, and after half a mile of level, there is in three-fourths of a mile a rise of 79½ feet, by 13 single and one double lock. From thence to Croydon, 7 miles, it is level. The locks are 60 feet long and 9 wide.

The Surrey rail-road commences on the south bank of the river Thames, near Wandsworth, and proceeds south-east about 10 miles to Croydon, and thence in a more southerly direction 16 miles to Godstow. It is a double railway. The inclination nowhere exceeds one in 120, or one inch in 10 feet. The engineer was William Jessop.

Between Gravesend and Rochester, a narrow neck of land projects northward about 12 miles, to nearly opposite Sheerness, where the Thames and Medway unite. Between London and Chatham and Rochester, by the present circuitous route, the distance between Gravesend and the latter place is upwards of 30 miles, and with easterly winds, it is difficult to get out of the Medway; but across the neck of the peninsula it is only about 7 miles. A canal is now making in this direction. It is partly along very flat marshy land, and 2½ miles through a chalk rib of land, which is intended to be passed by a tunnel. This canal commences on the south bank of the Thames at Gravesend, and will terminate in the Medway, a little below Rochester bridge. It is 28 feet wide at the bottom, 50 at the top, and has 7 feet water. There are only locks at the extremities, and the supplies of water are to be furnished by the Thames at spring tides.

We shall now proceed to describe the inlets in the vicinity of the Thames, and along the coasts of the Channel, until we reach the estuary of the Severn.

About 10 miles north of the Thames, the river Crouch is navigable about 12 miles to Hull Bridge, in Essex. The estuary of Blackwater is of more importance. From near Malden the Blackwater river turns to Coggeshall; the river Chelmer, from the same place, passes westward to Chelmsford, where it divides. The Chelmer and Blackwater navigation (6 and 33 George III.) commences at Collier's Reach. From low water in the basin to Heybridge Mill, on the Blackwater, 15¼ miles, there is a rise of 12 feet 8 inches; from this place to the Chelmer river, at Bailey Mill, 1¼ miles, the rise is 7 feet 3 inches; thence to Chelmsford, 10⅞ miles, the rise is 59 feet 5 inches. A short branch to Malden has a rise of 6 feet 5½ inches. The basin at Collier's Reach was opened for ships in Feb. 1796. From the northern side of the estuary the river Colne is navigable to Wivenhoe, where there is a dock-yard for building large ships. Smaller vessels may ascend to Colchester.

At Harwich is the Stour and the Orwell. In the former the tide flows 10 miles, and it is navigable 19 miles farther to Sudbury. In the latter the tide flows 13 miles to Ipswich; from whence the Stowmarket and Ipswich navigation proceeds (Acts 33 and 45 Geo. III.) 13 miles to Stowmarket. At little north of Harwich the Doben river is navigable 10 miles to Woodbridge.

On the south side of the Thames, in the isle of Sheppey, is the mouth of the river Medway, up which the tide flowed to Maidstone in Kent, 17 miles, until about 26 years ago, when locks and weirs were constructed below that town. Near Rochester bridge, 80 gun ships lie afloat at low water. This is considerably above Chatham dock-yard, to which this river affords a most safe and extensive harbour. Barges navigate to Maidstone, and even to Tunbridge; and a canal has been projected by the Wealds of Kent to Portsmouth. (Acts 32 and 42 Geo. III.)

To the south of the projecting point, named the North Foreland, the river Stour is navigable past Sandwich to the city of Canterbury, about 18 miles; but its mouth is so much perplexed by shifting sands as to render it unfit for large vessels, and it is otherwise of little use to Canterbury. This has led to the projection of an artificial canal from that city, but it has not yet been reduced to practice.

From hence, past Dover and Folkstone, the shore consists of bold chalk cliffs; afterwards, an extensive alluvial tract intervenes, until we arrive at the extremity of the South Downs range of chalk hills. This alluvial tract seems to have been formed by the tendency of the gravel beach to drift towards Dungeness; and the river Rother behind, flowing through a sandy country, between the range of chalk hills, has formed extensive deposits at its mouth. This tract was one of our earliest subjects of embankment and drainage. The space on the eastern side of the Rother, named Romney Marsh, is supposed to have been gained by the Romans. The same alluvial tract, under the name of Winchelsea and Pitt levels, extends considerably to the west of the Rother. But it is to be regretted, that the process of embankment within this estuary, by cutting off the back water, seems to have been the chief cause of the destruction of the several ports in it, famous in ancient times.

The river Rother is navigable through the haven of Rye, about 19 miles, to Robert's Bridge, with a branch 2½ miles to Winchelsea Bridge. In former times, this river is said to have reached the shore at Old Romney harbour; but in the reign of Ed. I. a new channel was made to Old Rye harbour, through which the tide flowed 23 miles, and, while suffered to do so, scoured the channel in such a manner, as to render it useful. But, with a view of improving the navigation, sea sluices were constructed, and these having obstructed the tide operations, the channel became choaked up and useless. In 1721, the sluices were removed, but the channel, it would seem, was not restored; for, in 1726, captain Perry cut a new channel, above a mile in length, to the sea, and about two miles from the town. This was 150 feet wide at the top, and 70 at the bottom. In 1763, Mr. Smeaton recommended that the old course should be entirely shut up, and all the water turned down through one, otherwise it would be choaked with silt. This recommendation, however, was neglected, and his prediction fulfilled; and in consequence of this occurrence, the tonnage, which was formerly paid toward maintaining this harbour of Rye, was, by an act of parliament, in 1797, transferred to Ramsgate harbour. A new cut was afterwards made, a quarter of a mile to the westward of the old blocked-up harbour, in order to force the water through the new cut, and a pier head and jetties were constructed, capable of protecting vessels of 300 tons. The spring tides rise 24 feet. On the Rother, coals, deal, timber, and merchandise, are imported; and oak timber and agricultural produce exported.

The inland navigation of this tract has been considerably extended since 1804, by the construction of the Royal Military Canal along the upper edge of these levels. It was originally intended as a line of defence, and as a rallying point for troops after a contest on the beach. Mr. Pitt was its great promoter. Perhaps a more useful purpose will be found as a navigation, for the conveyance of beach or shingle for the roads in the Wealds of Kent, and the transport of oak timber for ship-building, to Rye harbour. The line extends from the heights of Folkstone, in Kent, skirting the hills in the rear of Romney Marsh, to those of Fair Light Head, in Sussex, cutting off the whole flats of Romney Marsh and Pitt level, embracing 13 miles of assailable coast. It was commenced in 1804, under the direction of the quarter-master general. His assistant, colonel Browne, having the management of the practical operations, the Royal Staff corps executed the artificers' work; the Waggon Train the carriage. Navigators were employed in the excavation, and three steam engines were found insufficient to drain the works, and considerable difficulties were experienced: the whole was, however, completed in 1806. The canal and ramparts were to have been continued from the river Rother, under Pleyden Heights, to Rye, at Shorne Cliffe, and a tunnel driven through the shingle beach at Shorne Cliffe, 300 feet long, and 25 superficial feet in the section. The river Rother being fluctuating, a lock was necessary at that end of the canal. The line of defence beyond Rye, from Winchelsea to Cliffe End, through Pitt level, about 3 miles, was of the same dimensions as that already described; that is, 72 to 62 feet wide at the water's surface, 36 to 30 feet at the bottom, and 9 feet deep. Along the land side was a line of parapets, cannon proof, and a military road 30 feet in breadth. The canal line is laid out in a series of angles, so that successive reaches may flank each other. The locks are 72 feet long between the gates, and 16 feet wide.

A little to the westward of Beachy Head is the river Ouse, up which the tide flows 9 miles to the town of Lewes. It was embanked under an act of 31 Geo. III. And an act 30 Geo. III. was obtained, to render it navigable to Hammer bridge, about 22 miles above Lewes, with 3½ feet water, for boats 50 feet long, and 12½ wide. In 1793, a pier was built at the mouth of this river. Coals, deal, timber, and merchandise are imported, and chalk and agricultural produce exported.

In the same county, the river Arun navigation commences at Arundel haven, and proceeds 26 miles to New Bridge, near Wisborough Green. The Arundel canal branches off to the westward, about 11 miles from Midhurst, with a collateral cut of one mile at Haslingbourn bridge. This canal is the property of the earl of Egremont. Exports and imports are the same as on the Ouse.

In this quarter, a communication of considerable importance will soon be opened with Portsmouth and the river Arun, and the adjacent places, by means of a canal which commences in the island of Portsea, at the halfway houses, from whence it proceeds to Langston harbour, a distance of 2½ miles. Thus far the canal has a depth of 12 feet water. There are only two locks, which rise about 8 feet above water. They are each to be 110 feet in length, and 24 feet in breadth. From Langston harbour, the navigation is to cross the channel between Haylen island and Thorny, into Chichester harbour; from thence a canal line is carried across the country 12 miles to the river Arun, about 3 miles below Arundel. In this distance there are two locks at each end, rising 8 or 9 feet.

The canal from Chichester harbour to the city of Chichester is about 4½ miles, that is to say, 3 upon the main line, and a branch 1½. This district of canal has 8 feet water, and locks 18 feet wide. The rest of the canal has only 5 feet water, and locks 12 feet wide.

The creek which separates the island of Portsea from the main-land, and connects Langston harbour with Portsmouth harbour, is to be deepened to low water for the distance of about 2 miles, so as to receive the vessels which ply upon the before-mentioned navigation, and it is intended to work vessels across the tide-way, by means of steam boats.

To the north-west of Portsmouth is the great estuary of Southampton, at which place the Ilchin passes nearly due north, about 14 miles to Winchester. From this river at Netham, the Southampton and Salisbury canals branch off. One line proceeds along the eastern bank of the Anton river, and joins the Andover canal, which afterwards crosses the river, and is terminated at Andover; the whole rise is 176 feet. The branch to Salisbury leaves the Andover canal near Kingsbridge Mill, and after crossing the above mentioned river, proceeds to, and terminates at Salisbury. The acts are 30, 35, and 40 Geo. III. The engineers were, James Brindley, Robert Whiteworth, and John Rennie.

The river Avon, which proceeds by Salisbury to the sea at Christchurch, about 30 miles, is now, in a great measure, suspended by the above mentioned canal navigation. From the town of Christchurch the river Stour passes north-west 33 miles to Sturminster, in the county of Dorset. At Christchurch, the spring tides flow only from 5 to 7 feet, the neaps 4 to 5 feet.

In the county of Dorset there is little inland navigation. In Devonshire, the estuary of the river Exe is navigable to Topsham, whence a canal is formed to carry coasting vessels with coals, &c. to the city of Exeter. In 36 Geo. III. an act was passed for a canal from the river Exe at Topsham, across the counties of Devon and Somerset, to the river Tone, at Taunton. It was commenced, but has not yet been accomplished.

Still more to the westward, from the tide-way in the Teign river at Newton Abbots, the Stover canal goes to Newton Bushel, distant one mile, with a rise of 20 feet, and thence to Bovey 5½ miles, with a rise of 3 feet. The branch to Chudleigh is level. The imports are coals, shell-sand, and lime; the exports, potter's clay, Bovey coal, and agricultural produce.

On the southern coast of Devonshire, from Start Bay, near Dartmouth, the tide flows up the river Dart about 10 miles to the town of Totness.

At Plymouth, the various arms of that excellent harbour accommodate a considerable traffic; and north of Plymouth a canal was, by an act 43 Geo. III. made from the river Tamer, about 4½ miles, to the town of Tavistock, with a rise of 237 feet, and was opened in June 1817. A branch of 2 miles, rising 19½ feet, goes to the slate quarries at Millhill Bridge. A tunnel one mile and a half long, has been executed upon this canal, which does great credit to the ingenuity and skill of John Taylor, the engineer.

The Tamer river is the boundary between the county of Devon and Cornwall. It is navigable from the Hamoaze to near Calstock. At this place the Tamer manure navigation, authorized by 36 Geo. III. commences, and was intended to pass along the eastern side of the river for about 22 miles to North Tamerton. There have also been proposals for extending an inland navigation from this river to the Bristol Channel.

Along the whole of the southern coast of England, the inland navigations are chiefly employed in importing articles for the supply of the various adjacent districts, particularly coals, and in exporting oak timber and agricultural produce. From Devonshire are also exported slate, potter's clay, manganese, and the singular substance named *Bovey coal.*

Severn District.

The wide estuary of the Severn between Wales and Cornwall, opening to the Atlantic and to Ireland, unfortunately contains no good port on its shores, excepting Milfordhaven. The great rise of tide, however, and the increasing wants of the country, have led to the establishment of various tide harbours, and, at the mouth of its contributary rivers, towns of considerable commerce have gradually grown up. Caerleon, upon the Uske, though now decayed, was a city of note in the time of the Romans. Gloucester, in the main river, being, in its natural state, too far up for large ships, Bristol, upon the river Avon, became the chief mart for the commerce of the Severn, and although well situated for intercourse with Ireland, the west of Europe, and America, it has of late years been outdone by Liverpool. Notwithstanding this, Bristol contains a population of about 70,000.

The basin of the Severn is richly provided with mines and minerals, which, with the manufactures connected with them, have greatly promoted inland navigation. Cornwall abounds in copper and tin ores, and in slate and porcelain earth. The opposite coast of South Wales possesses coal, ironstone, and limestone, and the working and manufacturing of these create an increasing and extensive intercourse. South Wales, also, is the seat of a great proportion of the iron trade. As we ascend the Severn, coal, ironstone, limestone, and lead, continue within its basin, and often upon its very banks almost to its source. The porcelain and potteries of Swansea and Worcester draw their chief supplies from Cornwall and Devon.

The estuary of the Severn at Lundy island, is about 40 miles across; 60 miles higher, at the Holmes, it is only 7 miles; and it is here that the Severn is properly understood to commence. The length of its navigation from hence to Welch Pool, is reckoned 170 miles; at New Passage, 20 miles above the Holmes, the breadth is nearly two miles; 18 miles farther up, near Newenham, the river is contracted into a narrow channel, and from thence has a winding course of about 20 miles to Gloucester, where we find the first bridge.

At the Holmes, the spring tides rise	36 feet.
At Chepstow on the Wye, . . .	45
At Gloucester, about	6

		Distance.	Rise per Mile.	
From Gloucester to Worcester, the rise is	10 ft.	30 miles.	0 ft.	4 in.
From Worcester to Stourport . . .	23	13	1	9
From Stourport to Bridgenorth . . .	41.9	18	2	4
From Bridgenorth to Meadow Wharf, Coalbrookdale	29.6	11	2	8

There are no locks nor weirs on this river, and therefore the navigation is frequently interrupted in rainy seasons by flood water, and in dry weather from deficiency of depth in the fords; and the inclosing the low lands of Montgomeryshire causes the flood water to run off more rapidly than formerly. The acts of parliament respecting this river are, 19th Henry VII. 23d Henry VIII. 12th, 43d, 49th George III. The only improvements under these acts is, the making a horse towing-path from Bewdley, by Bridgenorth and the Meadow Wharf, to Shrewsbury. The barges which navigate this river are about 120 feet long, from 16 to 20 wide, and 5 feet deep, carrying upwards of 100 tons. The seven trows are 66 feet long, 16 wide, and 5 feet deep, carrying 75 tons: they are worked by a square sail, with a main and top mast, some of them 80 feet high. Numerous canals and rail-roads branch off from this fine river into the adjacent rich and productive counties.

The general structure of Cornwall renders it most accessible in its southern shores, but the great and necessary intercourse with Wales has promoted attempts at a more direct intercourse by the northern side. The Heyl river is navigable some distance from St. Ives Bay. A rail-road has been constructed, five miles from the harbour of Portreth, to the mines near Redruth. The harbour of Padstow, or Camel river, has a navigation eight miles to Wade Bridge, where the Polbrook canal commences, (37th George III.) and continues five miles to near Bodmin. The engineers were Messrs. Rennie and Murray. There have been other abortive attempts, as that of Edmond Leach, in 14th George III.; again, in 1795, for a canal from Bude Haven to the Tamer; also of Lord Stanhope, in 1793, from the same port to Holsworthy and Hatherbigh, in Devonshire. In 1775, a good deal of money was expended near St. Columb, on a narrow canal, but the scheme was abandoned.

On the Devonshire coast there is a natural navigation from the sea, up to Biddeford and Barnstaple, and barges proceed some miles higher.

In Somerset, between the limestone range of Mendip and the red ground in the south of the county, we have, as usual in that situation, a deep flat, occupied by a bog of peat, which from a very early period has been a field for drainage and navigation. The ridge called the Polden Hills, nearly divides this flat into two equal parts, the waters of which pass by different courses to the sea. On the south side, the Tone and Parret rivers, uniting at Borough Chapel, pass to Bridgewater, which is accessible to ships, and from thence pursue a winding course of 10 miles to the sea at Bridgewater Bay. The Tone river is navigable to Taunton, 16 miles above Bridgewater, and the Parret to Langport, where the Ilchester and Langport canal (35th Geo. III.) proceeds seven miles to Ilchester. The acts for the Tone and Parret navigations, are 10th and 11th William III. 6th Anne, and 44th George III. On the northern side of the Polden Hills, that part of the level drains by the rivers Brue and Axe; the latter river has been improved (42d George III.) and is navigable from the Lea, 11 miles, to Axebridge. See *Dugdale;* also *Agricultural Report of Somerset.*

Various projects have been formed for a communication across this country, between the Bristol and English Channels. The transport of coals from South Wales, instead of round the Land's End, has been the principal object. In 1769, a survey was made by James Brindley; and again, by an act of the 36th George III. for the grand western canal. It was proposed to pass by Taunton, Wellington, and Tiverton, to Exeter, through the great seat of the woollen manufactures. Another project by Brindley, was by Langport to Axeminster, on the Axe; but none of these projects have been carried into effect.

Leaving these proposed canals, we pass to the river Avon, the root of an extensive navigation, both natural and artificial. From the Severn we proceed by this river, between lofty limestone cliffs, eight miles to the new basin at Clifton, with a tide which rises upwards of 30 feet. In 1803, an act of parliament was obtained to improve the port of Bristol; in consequence of which ship locks were constructed adjacent to the hot wells, by which the portions of the Avon and Frome which entered the city were converted into extensive floating docks, for vessels of the largest dimensions. A new river course was cut through Radcliff Meads, into which the river falls over a regulating weir, and is crossed by two iron bridges, each 100 feet span. The engineer for these improvements was William Jessop.

Above Bristol the Avon continues navigable by locks, for about 20 miles to Bath, where the Kennet and Avon Canal commences, and forms a thoroughfare to the river Thames, with a variety of ramifications; which we shall now proceed to describe.

This canal commences in the Avon, a little above the old bridge of Bath, and thence proceeds—

To Sidney Gardens,	1 mile	by 7 locks, which rise	66½ feet.
To Bradford,	9 ditto,	level.	
Bradford lock,		1 lock,	10 ditto.
To junction of Wilts and Berks canal,	5 ditto,	level.	
To foot of locks at Foxhanger,	4½ ditto,	7 locks,	56 ditto.
To Devizes,	2½ ditto,	29 ditto,	239 ditto.
To Wooten river,	15 ditto,	original level	—— 371½ feet.
To summit level,	1 ditto,	4 locks,	33 ditto.
			—— 404½ feet.
Summit level,	2½ ditto,	including 700 yards of tunnel.	
To Crofton pumping engine,	1 ditto,	6 locks, fall 39 feet.	
To the wharf at Newbury,	15½ ditto,	25 ditto,	171 ditto.
		Total fall	—— 210 feet.

Where it joins the Kennet navigation, the total length being 57 miles.

It was originally proposed to pass the summit by a tunnel 5000 yards in length; but this was changed for a steam engine and four locks on each side the summit. The canal is 44 feet wide at the surface of the water, which is about five feet deep. The locks are 80 feet long and 14 wide. There are two considerable stone aqueducts over the Avon. The rugged nature of the county has rendered this canal difficult and expensive. The engineer was John Rennie. The acts are—34th, 36th, 38th, 41st, 45th George III.

From this canal branches off—

1. The Somerset coal canal, for narrow boats, for opening the coal field between the Mendip Hills and the Avon. From Dundas aqueduct to Milford two miles is level; from this point the northern branch passes eight miles to Paulton engine, rising 138 feet by nine locks. The southern branch has nearly the same length and rise.

2. The Dorset and Somerset canal, or Stour and Avon, by 36th and 43d George III. branches from the Kennet and Avon at Widbrook, near Bradford, passes by Frome, and is intended to proceed by Mincaunton and Stalbridge to the tideway in the Stour, near Sturminster. A branch from this canal, of nine miles in length, passes westward from Frome to the collieries of Nettlebridge.

3. The Wilts and Berks canal, of the 35th, 41st, and 50th George III. departs from the Kennet and Avon at Samington, passes near Milksham, Chippenham, Wotten Basset, and Wantage, along the foot of the Chalk Hills to Abingdon on the Thames. Its length is about 52 miles. Cuts are made from this canal to Chippenham, 1½ mile; to Calne, 3 miles; to Wantage, 1 mile. A branch also passes to the Thames and Severn canal near Cricklade. The Wilts and Berks is calculated for boats 70 feet long, and seven feet beam. It is 27½ feet wide at the surface of the water, 14 at bottom, and 4½ feet deep.

From Samington to the summit	21 miles,	rise 199 feet.
Summit level	8 ditto	
Thence to Abingdon	23 ditto,	fall 165 ditto.

The third great thoroughfare between the rivers Thames and Severn, and the first constructed, was the Thames and Severn canal, acts 23d, 31st, and 36th George III. It commences at the extremity of the Thames and Isis navigation, near Lechlade: thence to the eastern end of the Sapperton tunnel is 20¼ miles, in which 16 locks ascend 131 feet. This tunnel, upon the summit, is 4300 yards in length, 15 feet in width, and 250 feet below the highest part of the hill. From the western end of the tunnel to the Stroud canal, at Wellbridge, near Stroud, a distance of 7¾ miles, the fall is 241 feet by 28 locks. The canal is 42 feet wide at the water's surface, and 28 feet at the bottom, and about five feet deep. Vessels 80 feet long and 12 feet wide, carrying 56 tons, and drawing 3 feet 6 inches of water, pass this canal and down the Thames. Robert Whitworth and Joseph Clowes were the engineers. This canal was finished in 1789.

The Stroud canal proceeds eight miles, descending 102 feet by 12 locks. To the Severn at Framiload, this canal admits seven trows of 66 feet long, 16 feet wide, and 5 feet deep, carrying 75 tons. The acts were 2d and 34th George II. and 15th, 23d, 33d, and 37th George III. The first attempts to make Stroudwater navigable, was rendered ineffectual by the resistance of the millers, and the mismanagement of a scheme for transferring goods from one level to another by means of cranes. The engineers were Thomas Yeomen and Robert Whitworth.

Having again reached the Severn, we shall next notice the navigations on the northern shore of the Estuary. Milford haven forms an excellent harbour for vessels entering the British Channel. It is navigable to Haverfordwest; and near to Narberth, a tract of stone coal, and culm, extending from St. Bride's Bay to Tenby, is thus rendered accessible. In Carmarthen Bay there are also natural navigations to St. Clares in the Towe, and to Carmarthen on the Towey.

At Kidwelly commences the great coal basin of South Wales, extending to Swansea, Bridgend, Caerphilly, and Pontypool, and northward to the boundary of Brecknockshire. The north-western seams are chiefly stone-coal; burning without flame, they are extensively used in malting, &c. The more southern beds are bituminous, and extensively exported to the west of England, Ireland, and France, &c. In the north-eastern parts, the coal being farthest from the coast, has been chiefly wrought for smelting ironstone: inexhaustible beds of which accompany the coal strata. The quantity of iron produced in this district is nearly 200,000 tons annually. Near Swansea, and at other places along the coast, furnaces are constructed for smelting copper ore, baking porcelain, &c. There are also manufactures of tin plates and iron-wire, rolling-mills, &c. These operations have led to the formation of various canals; and when these have been found impracticable in the hilly country, extensive rail or tram-roads, with inclined planes, have been adopted.

At Kidwelly a short canal was early formed by Mr. Keymer, from his coal works to the shipping-place, on the Kidwelly river; since that time it has been extended by an aqueduct over the Gwendreth Vawr, to some collieries to the eastward.

The Burry river is navigable for 10 miles to Loughor. From the dock or harbour at Llanelly, the Carmarthenshire railway (Act 42d George III.) extends 15 miles, through a productive coal country, to the lime works near Llandebie; and on the eastern side are railways to the extensive coal works of General Waide.

At Swansea, the river Towe is navigable for about three miles among the copper works. The mouth of the river has been made a good tide harbour, by piers constructed under the direction of Captain Huddart. From the town the Swansea canal proceeds along its western bank, for about 18 miles to the Henoyadd lime-works. The total rise is 411 feet. Several railways communicate with this canal to the coal works on the other side of the valley. Act 34th George III. Engineer, Thomas Shearsley.

The Oyster-mouth railway proceeds from Swansea, seven miles along the coast, south-west to the village of Oystermouth, intended chiefly for carriage of limestone. On the eastern side, and parallel to the river, a level canal of three miles proceeds to the collieries of Mr. Smith at Llanfarnlet.

At Neath the river is navigable four miles to Swansea Bay. A canal has, however, been formed along the side of it, to a shipping place farther down the river. The same canal proceeds up the valley to Aberfergwn, where a railway joins it from the head of the Aberdare canal, a branch of the Glamorganshire canal. The total length of the Neath canal is about 14 miles. Various railways branch from it into the neighbouring collieries. Acts 31st and 38th George III. Engineer, Thomas Shearsley.

On the western side of the Neath river, the Crumlin canal, a level of about 3½ miles, proceeds from the shipping place at Britton Ferry, through the Crumlin Bog to New Chapel collieries. This canal is private property.

At Cardiff is the mouth of the Taff river, along the side of which has been constructed the Glamorganshire canal, under acts 30th and 36th George III. for the export of pig and bar iron from the Merthyr Tydvill works, also for coal. The canal departs from the Taff by a sea lock for ships of 300 tons, into a basin; and from thence, but of smaller dimensions, passes along the eastern side of the river, to the junction of the river Cynon, near Quakersyard, where it crosses the Taff by an aqueduct. Near the same place branches off the Aberdare canal, up the vale of Cynon, and the Merthyr and Cardiff railway on the eastern side of the Taff. From this aqueduct the canal ascends by a stair-case of locks, and continues on the western side of the river to the Cyfartha iron-works, the total rise being nearly 600. In the upper part of the canal there is frequently a want of water; a supply is therefore obtained from the river by means of a steam engine some miles below Merthyr. This circumstance led to the formation of a railway parallel to it, chiefly for the iron works of Plymouth, Pendarran, and Doulais; but this railway has not been carried lower than Quakersyard, being about nine miles from its commencement. These canals and railways are carried through a very rugged country.

The Aberdare canal, 33d George III. is a branch of the above, and passes 7½ miles north-west of Aberdare, where railways commence, passing the iron works of Abernant, Aberdare, and Hirwain, and thence to the summit of a precipice near the Neath Valley, where an immense inclined plane completes the communication with the Neath canal. Up this inclined plane the waggons are dragged by a high pressure engine of Mr. Trevithick's construction.

The last congeries of inland navigations in this quarter terminates at Newport, near the mouth of the river Uske. It proceeds up that river to the town of Brecon, having various branches.

The Monmouth canal, 32d, 37th, and 42d George III. from the lower part of this navigation, commences at Pillgwèlly on the Uske, and passing Newport to Malpas, divides into two branches. Of these, the one follows the channel of the Ebbw river, 11 miles to Crumlin Bridge, whence lines of railways proceed up the Ebbw 21 miles to Ebbw Vale and Beaufort iron-works, with branches to Sirhowy, &c. also up the Ebbw-vach to Nant-y-Glo iron-works. The eastern, or main line, is from the Uske to Pont Newydd near Pontypool, 12½ miles, rising 447 feet; whence a railway proceeds 5½ miles, rising 610 feet to Blaen-Avon furnace. Various other branches of railways are connected with the navigation, but the most important is the Sirhowy line. This railway commences at the Monmouth canal, at Pillgwelly, and passing through Tredgar Park up the Ebwy river, at Risca crosses that river by a bridge of 16 arches, following afterwards the course of the Sirhowy river by Tredgar and Sirhowy iron-works to Trevill lime-works, about 28 miles. A branch proceeds to Romney iron-works; and from the same place the Brinore railway is continued over the Black Mountain to the vale of the Uske at Brecon; and from thence to Hay on the Wye, by means of which the price of coals in the upper parts of the counties of Hereford and Radnor has been greatly reduced. The Sirhowy railway is accompanied through all its extent by a good turnpike road. There are also branches from the railway to the several collieries, and likewise to the Monmouthshire canal in two places. On that canal the locks are 80 feet long and 10 feet wide.

At Pontypool, the Brecknock and Abergavenny canal, 33d and 44th George III. passes from the main Monmouthshire line, crossing the Avon river by an aqueduct, passing through a tunnel of 220 yards, and proceeding along the high ground to the west of the Uske 14½ miles, and level; thence to Brecon 18½ miles, with a rise of 68 feet; thus making the whole extent of the main line from Newport about 45 miles. From this canal a railway passes by a bridge over the Uske to Abergavenny. There is a railway branch to Uske, one to Hay, as already mentioned, and various others to the coal and iron works. At the iron works near Pontypool there are some lofty inclined planes.

The next navigation connected with the north shore of the Severn, is the river Wye, which falls in at Chepstow. It ascends by a very crooked course through the counties of Monmouth and Hereford, and is navigable to Hay on the eastern side of Brecknockshire, a distance of 85 miles. At Chepstow, the tide often rises 45 feet. This renders the lower parts dangerous to navigate; and the upper parts are incommoded by shallows. There is a horse towing-path along the river. The chief objects are the importation of coals, fir timber, deals, and groceries; and the exportation of oak timber and agricultural produce. From the Wye, near Mitchell Dean, a railway has been laid through the forest of Dean to Lydeny, on the Severn, opposite Berkeley, and another branch from this by Colford to Monmouth; and nearly opposite to the Stroud canal a third railway has been made, five miles, to the collieries in the Forest.

Having arrived again at the channel of the Severn, we find, on its southern bank, the Berkely and Gloucester canal. By this it is intended to cut off the windings of the river in that place, the distance by the river being now 28 miles, whereas by the canal it will be only 18¼ miles. It is connected with the river at each end by a ship lock. The breadth of the canal is about 60 feet at the surface of the water, and the depth of water 18 feet. It crosses the Stroud canal upon the same level. The works are far advanced, and they promise to effect a very beneficial revolution in the lower part of the Severn, by transferring to the city of Gloucester a great portion of the trade of that great river, and its extensive connections. The acts for this canal are 33d, 37th, and 43d George III. Robert Mylne was originally engineer, and Thomas Telford has lately been employed.

Opposite Gloucester, branches off the Hereford canal, from the Severn to Ledbury, 18 miles. The ascent is 196 feet. At Monkside, 8½ miles distant, is the summit level. At Witherington Marsh, three miles farther, there is a fall of 30 feet; and thence to Hereford, six miles, is level. At Oxenhall there is a tunnel 2192 yards in length; at Canon Frome another 1320; and a third near Hereford 440. The acts are 31st and 33d George III. Engineer, Joseph Clowes. Trade, coal, cyder, and agricultural produce.

From the eastern bank of the Severn, at Tewksbury, branches off the river Avon navigation, which proceeds along a crooked course through Worcestershire to Stratford, in Warwickshire, a distance of 40 miles. The whole navigation is the property of George Perrot, Esq.

At Worcester, the Worcester and Birmingham canal passes off, but its description belongs to the central district.

A little above Worcester is the Droitwich canal. It connects with the Severn at Hawford, and terminates at Chapel Bridge, Droitwich, a distance of 5¾ miles, rising 59½ feet by eight locks. It is supplied by salt water. Its trade consists in coals to boil the salt brine, and it is used for the export of salt. Act 8th Geo. III. Engineer, James Bradley.

At Stourport falls in the Staffordshire and Worcestershire canal, but it also belongs to the central district.

From the western side of the river, opposite Stourport, passes off the line of the Leominster canal. Its direction is generally west; but it is very crooked, and mostly through a very rugged country, 45¾ miles to the town of Kingston, in Herefordshire. About 20 miles in the middle part only are executed; but this includes a very considerable aqueduct over the river Teme, with several locks, side cuttings, and embankments. The acts are 31st and 36th George III. Engineer, Thomas Dadford.

From Stourport upwards 25 miles to Coalport, the course of the Severn is generally bounded by high steep banks, and the country on each side is hilly, so that no collateral navigation occurs in that distance. At Coalport is the lower termination of the Shropshire Canal. This work forms a singular epoch in the history of English canals; for the country over which it passes being extremely rugged, and its elevation high and abrupt, and there being likewise a scarcity of water, the modes formerly practised were quite inapplicable. These difficulties suggested the adoption of a plan then lately introduced into that country by Mr. William Reynolds, at Ketley ironworks, which consisted in forming canals upon different levels, terminating at steep banks, and conveying the boats between them by means of inclined planes, constructed upon the slope of the above-mentioned banks. In pursuance of this new mode, the commencement of the Shropshire Canal was formed by a canal about three quarters of a mile in length, along the east bank of the Severn, just above the reach of the floods, and leaving room to stack the coals between it and the river. From this level, up the face of a steep bank, was constructed an inclined plane 350 yards in length, and 207 feet in perpendicular height, with a strong double rail-road upon it, to admit boats loaded with five tons, and their carriages. From the top of the inclined plane, a level canal was made 1¾ miles to the bottom of the second, or windmill inclined plane. This is 600 yards in length, and 126 feet in height. From the top of this, to the top of the Rockwardine Wood inclined plane, a distance of five miles, is the summit level. This last mentioned plane is 320 yards in length, and 120 feet fall. Beyond this the canal extends 100 yards, which is level. At Southall Bank, three quarters of a mile from the top of the Windmill inclined plane, a branch 2¾ miles passes westward to Briarley Hill, where formerly there was a communication with the Coalbrookdale works, on a much lower level, by means of crates or boxes descending through pits; but in preference to that mode, inclined planes are now employed. About 1¼ mile from the top of the Rockwardine Wood inclined plane, a small canal branches off to the Ketley iron works, and it was here that Mr. Reynolds, in the year 1788, constructed the first inclined plane with a fall of 73 feet, for eight ton boats. The chief purposes of the Shropshire canal are the exportation of iron and coal from the adjacent works, and the importation of limestone for the blast furnaces. The canal was filled, and has since been supplied with water by steam engines, which drain the coal mines. The act was 28 Geo. III. The whole was designed by Mr. William Reynolds. Mr. Henry Williams was the resident engineer. It was completed in 1792.

At the north-east extremity of the last canal, commences the Shrewsbury canal, which, for about one mile, is level. At Wombridge there is an inclined plane of 223 yards in length, and 75 feet fall. From the bottom of this to Longdon, a distance of 4¾ miles, there is a fall by lockage of 79 feet. Across the river Tern, at Longdon, there is an aqueduct of cast iron, the first made for a navigable canal. From Longdon the canal proceeds by Roddington to the neighbourhood of Atcham, where it passes a tunnel 970 yards long, and afterwards along the base of Haughmond Hill, and the north bank of the Severn, to Shrewsbury. The distance from Longdon is 12 miles, and level. The chief use of this canal is to supply the town of Shrewsbury with coal. Its act is 33 Geo. III. Thomas Telford was the engineer employed for the aqueduct and tunnel, and completing the canal.

The Shropshire and Shrewsbury canals, together, form a general line of communication through a populous and industrious district, the description of which has led us to pass, in regard to locality, a work of the Marquis of Stafford. From the bottom of the Rockwardine Wood inclined plane, a short canal of seven miles has been constructed by that nobleman to Pave Lane, near Newport, with a branch, on a higher level, to his lime works at Lillieshall, which formerly communicated with the main line by pits, but now by an inclined plane.

From Shrewsbury northwards to the rivers Dee and Mersey, the country is intersected by the Ellesmere canal, an arm from which, under the name of the Montgomeryshire, occupies the upper part of the Vale of the Severn; but as this sort of navigation is not yet unconnected with the Severn, and much employed in the intercourse with Liverpool, it seems most proper to refer its description to the canal communicating with the river Mersey.

North-west District.—The Mersey.

The extensive basin of country facing that part of the Irish Sea which occupies the space between the northern coast of Wales, and the county of Cumberland, is bounded on the north-east by the range of elevated ground extending from Derbyshire to Cumberland; on the south-west, by the mountains of Wales. Its middle rises gently through a rich country to the central plains of England. The hills of Wales and Cumberland produce slate and mines of copper; within these is a basin of lime-stone producing abundance of lead and zinc; next comes immense strata of coal, and its accompanying iron-stone, skirting the whole basin, and to the north-east especially, expanding over such a vast extent of country as to appear altogether inexhaustible. The middle tract is covered with a sheet of red marly sandstone, containing also vast beds of rock-salt, plaster-stone, and potters' earth. These natural productions have made this district the seat of manufactures; and the foreign trade having introduced cotton and other colonial produce, the various manufactures of the former material are here more extensively pursued than perhaps in any other part of the world.

The seaport of Liverpool is the great market for the labours of all this district, and the focus of an immense inland navigation, whereby water communications have been formed to the borders of North Wales, to the Severn, the Thames, the Trent, the various branches of the Humber, and into Westmoreland. By means of these, and their numerous ramifications, a communication is formed, not only with every town of any note, to every scene of mining and manufacturing industry, but even through a vast extent of country purely agricultural.

Along the shore of Wales itself we only find the Menai Strait partaking of the nature of inland navigation. It separates the island of Anglesea from Carnarvonshire. It is navigable for large vessels, though there are bars at its extremities. Spring tides rise about 21 feet. Slates from the quarries above Bangor and Carnarvon, being the chief object of trade, have led to the construction of iron rail-roads, with several inclined planes.

On the eastern frontier of Wales, from Shrewsbury northwards to the river Mersey, the country is intersected by the Ellesmere and Chester canal, which consists of two great lines crossing each other near the town of Ellesmere, at nearly right angles. These lines pass through the counties of Salop, Denbigh, Flint, and Chester, and will, when completed, form a junction of the three great rivers, Severn, Dee, and Mersey. This is perhaps the only instance, in England, in which a canal of great extent was undertaken chiefly for agricultural purposes, and where the supply of towns and manufactories was a secondary consideration. Coal, lime, slate, and iron-stone, lie along the skirts of the Welch mountains, and the extensive and populous agricultural districts to the south and east create a constant demand for these articles. The more remote manufacturing districts in Stafford, Salop, and Lancashire, are markets for agricultural products; and the ports of Liverpool and Bristol furnish articles from foreign countries. Aware of these circumstances, the principal land owners of the adjacent districts, in 1792, formed a great company, and in 1793 the first act was obtained. During the progress of the works, several other acts have been found necessary, and by the last, the Chester canal to Nantwich was united to this, and made a joint stock.

The southern extremity of the Ellesmere canal is at Bayley Bridge, a north suburb of Shrewsbury; from that place to Almond Park, a distance of 1 mile 7 furlongs, the rise is 107 feet. Northward by Basschurch, Weston, and Shade Oak, to the bottom of the Frankton Locks, a distance of 14 miles 5 furlongs, is level. At Frankton four locks ascend 30 feet; thence to New Martin Moor, 2 miles 7 furlongs, is level. Here two locks ascend 13 feet to the summit of this canal. From this place the canal passes by Chirk to Pontcysylte, 8 miles, and thence along the water line, up the north bank of the river Dee, to Llandisilio, 6 miles, making this summit level 14 miles. On this summit the depth of the valleys through which the rivers pass, the steepness of the banks, and the general ruggedness of the surface, opposed great obstacles to canal making. At Chirk it passes over an aqueduct 600 feet long, and 65 feet high; (see Plate CCCCXV.) and thence to the south bank of the Dee, it passes one tunnel 500 yards, and another of 200 yards in length, and about one mile of very deep cutting. It then passes the valley of the Dee, upon the greatest aqueduct and embankment ever made for a navigable canal. The embankment is 1500 feet long, and 75 feet high at one end. The aqueduct is 1007 feet long, and 126 feet 8 inches high. As these will be particularly described afterwards, and illustrated by Plate CCCCXV. we shall at present only observe, that their modes of construction are new, and proved by experience to be suitable. The water line, six miles in length, along the romantic banks of the Dee, up the Vale of Llangollen, is cut through steep rocky banks to the river Dee at Llandisilio, where a stone weir and sluices regulate the water for the feeder, while the river itself, collecting the streams from an extensive valley in the counties of Denbigh and Merioneth, and having its source in the lake named Bala Pool, which is nearly four miles in length, affords provision for inland navigation seldom equalled, and all this too above the summit of the countries through which the canal passes, so that supplies can be distributed to the north, the south, and west. Adjacent to the water line are very extensive limeworks and slate quarries. A regulating wier enables Bala Pool to retain flood water, and afford supplies to the river Dee in the summer months.

At Pontcysylte, on the north bank of the river Dee, there is an extensive basin, and from it a double railway ascends gently past Mr. Hazledine's iron works, and through numerous collieries, to Ruabon Brook, a distance of about three miles. The main supply of coal is from this quarter, and, considering the vicinity of ironstone, coal, and limestone, and the facility of water conveyance, it is reasonable to expect that other iron-works will be constructed. The south bank of the Dee at present affords the greatest supply of limestone which passes along the canal; but on the north side of the Llangollen valley, the range of Glucig rocks form an inexhaustible stock of excellent limestone.

Having described one of the canal lines, we must return to Frankton Locks, where the other line crosses. From Frankton westward, a line passes near Woodhouse, crosses the Shrewsbury and Holyhead Road, and extends to Aston Moor, where it descends 19 feet by three locks. Proceeding thence, it crosses Macsbury Marsh, and under Crickheath and Llanymeneech lime rocks, to the eastern bank of the river Verniew, where it joins the Montgomeryshire canal. From Frankton to this termination the distance is 11 miles 1 furlong. In this distance four railways, private property, are laid to bring coal and lime to the canal.

From Frankton eastward, the canal proceeds four miles to Ellesmere, where a short branch passes off to the town wharfs and warehouses, which are the property of the Earl of Bridgewater. Opposite to this branch stands the canal office, where all the business is transacted. From Ellesmere the canal proceeds through a short tunnel, and along the shores of the meres or lakes to Hampton Bank, where limekilns are constructed. From thence it passes to and across Wexall moss, on the eastern side of which the Prees branch, of three miles passes to other lime works. From Wexall moss the main line proceeds to Grindley-brook lime works, after extending a short branch up to the wharfs at the town of Whitchurch. From Frankton to this place, a distance of 17 miles, and including the Prees and Whitchurch branch, 21 miles, is without a lock; and here it is worthy of notice, that from the upper end of the water line at Llandisilio, to Grindley Brook near Whitchurch, the canal passes upon the summit level of the country for a distance of 38 miles, with only 13 feet of lockage.

From Grindley Brook the canal passes down a valley for some distance, separating the counties of Salop and Chester, afterwards by Wrenbury lime works to the Chester canal at Harleston, about two miles from Nantwich, the distance being 12 miles, with a fall of 128 feet by 19 locks. Thus far the canal and locks are formed for boats of 70 feet in length, and 7 feet in width, and has 4 feet 6 inches of water.

We now enter the Chester canal, which commences near the town of Nantwich, and passes, in a north-west direction, between Beeston Castle and the town of Turperley, and thence, in nearly a direct line, to Chester, where it joins the Wirrall line of the Ellesmere canal, at the Tower Wharf; and passing three locks and a large basin, falls into the river Dee. The distance from Nantwich is 20 miles, the fall 170 feet. This canal is made for 70 feet boats, and 14 feet beam. It has 4 feet 6 inches water, which is supplied from the Ellesmere summit level. Its acts are 11 and 17 Geo. III. Was begun in 1772, and completed in 1776. But the river Dee, to the westward, being a bad navigation, and the river Weaver and Grand Trunk Navigation counteracting its operations to the eastward, and the Nantwich salt mines having failed, this excellent canal lay totally unemployed, until the Ellesmere was connected at each extremity with the one in 1796, the other in 1805, and of which it now forms a component part.

From the Tower Wharf at Chester the canal passes in a northerly direction across the low land of the Hundred of Wirrall, to the south bank of the river Mersey, where it terminates in a small bay now called Ellesmere Port. This distance of 9 miles is level. At Ellesmere Port it enters the Mersey by three locks, and at Chester, as we have already said, communicates with the Dee by three locks. It was opened in 1796, and is made for river barges of 14 feet beam. Its purposes are chiefly commercial, with Liverpool and Manchester.

To complete the southern part, 11 miles remain to be made from Weston Lullingfield to Shrewsbury. The engineers were, John Duncombe, who traced the original lines: William Jessop, who was occasionally consulted in obtaining the acts, and during the early part of the canal operations; and Thomas Telford, who planned the aqueducts, and under whose directions these, as well as all the canal works, were executed.

The Dee river is navigable from Chester to the Irish Channel, a distance of about 22 miles, of which the lower part is a wide estuary, incommoded by shifting sands, and an extensive bar. From Flint to Chester it was formerly a very crooked channel, and so shallow, that vessels of 20 tons only could come to the town. Large ships were obliged to lie 10 miles below. In 1740, there was a new channel made in a straight direction, by which, at spring tides, vessels of 250 tons came to the city wharfs. This improvement was effected by a company of adventurers, who, by changing and embanking the river channel, obtained a great extent of land now under excellent cultivation by the judicious management of Mr. Thomas Wedge, the river Dee Company's agent. There is a considerable trade in coals and lead upon this river, but the communication with Liverpool and Manchester is carried on chiefly by the Wirrall line of the Ellesmere and Chester canal. Above Chester bridge a weir is constructed across the river for the use of large mills. This prevents an immediate communication with the tideway. There is however a considerable traffic between Chester and Bangor, (about 16 miles.) Grain, malt, and oak timber are sent down. Above Bangor the river is not navigable. The rise from the tideway at Chester to the surface of the Ellesmere canal, on its summit level on Pontcysylte aqueduct, at the Vale of Llangollen, and consequently six miles up that vale to the termination of the water line at Llandisilio, is 311 feet.

We must now return to the most western branch of the Ellesmere canal, at Llanymeneech, where the Montgomeryshire canal commences. This, having descended by two locks, crosses the river Verniew by a very considerable stone aqueduct, and proceeds to Gwernfelu, where a branch turns up the Guilsfield Valley. The main line descends by two locks into the valley, and having crossed it, immediately again ascends, and skirting the banks of the Severn, passes the town of Welshpool to Garth Mill, distant 16 miles from its commencement, having a fall of 33 feet into Gwernfelu by four locks, and a rise of 71 feet from the said valley to Garth Mill by nine locks. This canal receives its supply of water from the rivers Severn and Tannat. From Garth Mill the canal, by a new act, has been extended 9 miles, with a rise of 48 feet to Newtown. The chief purposes of this canal are the importation of coal, lime, and merchandise, and the exportation of oak timber and agricultural produce. First act, 34 Geo. III. Engineer, Thomas Dadford.

Returning to the shores of the river Mersey, we find the river Weaver navigation. This river has a very crooked course past Nantwich, Windsford, Northwich, and Frodsham Bridge, to the Mersey, about a mile below Runcorn,—all in the county of Chester. In the course of 24 miles, up to Windsford Bridge, it has only a rise of 42 feet; but this gentleness of current has created sinuosities and fords, and thereby obstacles to the navigation, and the intercourse, on account of the numerous and extensive salt mines, being very great. Some of the country gentlemen obtained an act (7 Geo. II.) authorizing the construction of side-cuts, locks, and weirs. By these all the navigation above Frodsham Bridge was greatly improved; but below that place there was a rapid tideway, and a shifting bar of sand banks. This has of late years led to the construction of an artificial canal along the eastern bank of the river, of about 4 miles in length, commencing opposite Sutton lock, above Frodsham Bridge, and terminating in the river Mersey at Weston Point, a little way below Runcorn, where there is a tide lock, an extensive basin, and a pair of gates to admit of vessels floating into it as soon as the tide will carry them. At the upper end, where this canal connects with the river Weaver, there is a regulating lock. The length of the river Weaver locks is 80 feet, and breadth 18 feet. The vessels are 60 to 70 feet in length in the keel, and from 15½ to 16½ broad in the beam, and draw, when loaded with 60 to 80 tons, 5½ to 6½ feet water. There are about 260 vessels or flats which trade upon this navigation. They are chiefly the property of the salt proprietors. Rock salt pays, by the Excise account, 65 lbs. to the bushel, 40 bushels to the ton. The tonnage of coals has been reckoned at 24 cwt. to the ton. The tonnage was originally 12d. per ton for the whole or any part of the navigation. Subsequently 2d. more per ton was allowed until the expense of the Weston Point extension was defrayed. A little below Northwich there is a communication with the Grand Trunk canal by inclined planes. The revenue in 1814 was L. 24,000. The surplus produce, after maintaining the canal works, goes to defray the expense of the public works of the county, which greatly relieves the county rates.

We shall next proceed to notice that justly celebrated undertaking, the Duke of Bridgewater's canal, which is not only singularly valuable on account of the very complete accommodation it affords to the country through which it passes, but inestimable as the model and root of the canal navigation of England. The attempts previously made merit no attention, in comparison with the bold and successful projects of the distinguished nobleman under whom it was contrived and executed. He at once proceeded in a complicated work, on the most comprehensive scale, and by his exertions and example turned a great portion of British talent and capital into a direction which has, in a few years, pervaded and improved the whole kingdom, and been a principal means of extending its commerce and manufactures.

We shall not stop to inquire whether the Duke of Bridgewater, when he conceived his truly magnificent plans, travelled to examine the canals in Holland, France, and Italy. He was to blame if he did not; but when a nobleman of his rank and fortune breaks through existing prejudices, forms a project of great difficulty, risk, and expense, acquires information adapted to his measures, chooses agents thoroughly qualified for the parts they were to perform, and, what is perhaps more than all the rest, has the good sense and firmness to confide in them through good and bad report, and all the occasional and frequently serious disappointments to which new and great attempts are subjected, we must acknowledge, with exultation, that this man justly merits the title of *Father of English Canal Navigation.*

The original destination of this canal was, to convey coals from the Duke's mines at Worseley to the town of Manchester, and for which the act of 32 George II. was obtained; but when the canal had reached the Warrington Road to Manchester, another act was procured to vary the line, by crossing the river Irwell at Banton Bridge, and proceed to Manchester, up the south side of that river, with a branch to Longford Bridge. In three years that act was followed by a third, to carry the canal from Longford Bridge, past Altringham, to the river Mersey at Hempstones, in the county of Chester; but this was in part changed, and the canal was finally carried by Preston Brook to Runcorn. In 1795, by an act 35 George III. an extension was made from Worseley Mill to the town of Leigh in Lancashire, with a branch to Chat Moss. Excepting 82 feet of rise by ten locks, in the distance of 600 yards, at Runcorn, the whole of the navigation, which is about 45 miles, is upon one level, to which when we add 18 miles of the Grand Trunk from Preston Brook, making 63 miles, besides what is under ground, in the Worseley coal mines, which cannot be less than 10 miles, we have the extraordinary extent of 73 miles of canal navigation upon one level. Combined with this advantage, we may add, that the Grand Trunk, and all the canals at Manchester connected with the western sides of the ranges of mountains which separate Lancashire and Yorkshire, finally discharge water into the Duke's Canal, and thereby insure a superabundant supply for all its purposes. The locks at Runcorn were opened in 1772. In 1776 the whole of the works from Worseley to Manchester, Preston Brook, and Runcorn, were completed. The extension to Leigh was made in 1795.

The determination of preferring one level, led to the construction of tunnels, aqueducts, and embankments of very considerable magnitude, which, in that infant state of canal operations, were truly formidable. Nothing, however, could shake the fortitude and perseverance of its illustrious patron, or baffle the ingenuity and exertions of his engineer, James Brindley, and his faithful and sagacious agent, Mr. John Gilbert. The intercourse upon this canal is incredible; for besides the coal trade to Manchester and Leigh, the intercourse with Liverpool, and, by means of the Grand Trunk, with all the midland counties, is unceasing and very extensive. The passage boats also bring a very considerable revenue. The whole annual produce, including the Worseley mines, is said to amount to from 70,000*l.* to 80,000*l.*

The river Mersey, for 20 miles above Liverpool, is an open estuary, in some places four miles in width; the tides are high and rapid, spring tides at Liverpool rising about 30 feet, and 16 at Runcorn Gap. The following navigations connect with this part of the river. Immediately below Warrington the Sankey canal enters; a little above Runcorn the Mersey and Irwell new cut; at Runcorn the Duke of Bridgewater's canal; and a little below it the river Weaver navigation at Weston Point. About ten miles farther down, on the Cheshire shore, the Ellesmere canal falls in at Ellesmere Port, and at Liverpool the Leeds and Liverpool canal.

At Runcorn, commences the powers of the Mersey and Irwel Navigation Company, under an act 32 Geo. III. These rivers have been improved by locks and weirs, so as to complete the navigation up to the bridge between the town of Manchester and Salford. The total rise is about 70 feet. In 1758, the price of carriage on this river between Liverpool and Manchester was 12 shillings; but on the completion of the Duke's canal it fell to six shillings.

From the Duke's canal at Manchester proceeds the Rochdale canal, which passes by the town of Rochdale and the northern extremity of the high land, named

Blackstone Edge, and terminates in the Calder and Hebble navigation at Sowerby wharf, Halifax, the whole length being 31½ miles. From Manchester to the summit it ascends 438 feet in about 14¾ miles. The summit is 5¼ miles; and to Sowerby wharf the distance is 11¼, with a fall of 275 feet. It is supplied with water by means of three large reservoirs, which collect flood water from Blackstone Edgehills. The locks are for boats of 14 feet beam. The whole navigation was completed in 1804. The acts are 34, 40, 44 Geo. III.

From the Rochdale canal at Manchester branches off the Ashton and Oldham canal. It passes by Fairfield, and terminates in the Huddersfield canal at Duckenfield bridge. Its length is 11 miles, and rise 152 feet. It also joins the Peake Forest canal by a branch of one-fourth of a mile. There is another branch of one mile up to the town of Ashton, and another of 3¾ miles to New Mill and to Park collieries. From the Ashton main line at Draysfield, a branch of six miles passes to the town of Stockport; and from that a branch of three miles goes to Beatbank in Denton. All these canals are for boats of seven feet beam. The Ashton line was completed in 1796, and that to Stockport in 1797. The acts are 32, 33, 38, 40, 45 Geo. III.

From the Ashton proceeds the Peake Forest canal. It passes in a south-east direction 17 miles to Chapel Milton, and thence by a railway and inclined plane six miles to Loads Knowl lime quarries in the Peak. There is a canal branch of half a mile to Whaley bridge, and a railway branch of 1½ mile to Marple. This canal being through a very rugged country, has expensive works, one an aqueduct of three 60 feet arches, each about 100 feet high; and the inclined plane 515 yards long, and 204 feet fall. The acts are 34, 40, 45 Geo. III. Engineer, Benjamin Outram.

Nearly from the same point as the last, the Huddersfield canal departs from the Ashton, pursuing a north-east direction across the ridge which here separates Cheshire from the West Riding of Yorkshire, which it passes by a tunnel above three miles in length, but mostly in rock. After passing the tunnel, the canal descends to Huddersfield. The total length is 19¾ miles: that is to say, from the Ashton canal to the western end of the summit about 8½ miles, with an ascent of 334 feet by 31 locks. The summit is 3¾ miles, occupied chiefly by the tunnel. From the eastern end of it to Huddersfield is about 7¼ miles, with a fall of 436 feet by 42 locks. The canal is supplied by reservoirs. The principal ones are in the Stannage hills, and one on the eastern side, above 70 feet deep, at Slaithwaite, which is below the summit level. The whole of the canal forms a striking instance of British enterprise and industry.

Sir John Ramsden's canal is a short link of 3¾ miles of length, with a fall 57½ feet by 9 locks, between the Huddersfield and Calder and Hebble navigation. The locks are 64 feet long, and fifteen feet wide.

From the river Irwell in Salford, the Bolton and Bury canal ascends to a basin in Salford; from thence for four miles the canal is level. In the next three miles it ascends by 12 locks; thence to Bolton four miles it is level. From Bolton a branch proceeds 4 miles to Bury. The whole rise is 187 feet. The locks are for boats 14 feet beam. The country over which it passes is very rugged. The acts are 31, 41 Geo. III.

From the north shore of the Mersey, a little below Warrington, the Sankey navigation proceeds to the collieries near St. Helen's, a distance of 12½ miles, with a rise of 78 feet, by eight single and two double locks, for river barges. The depth of water is 5 feet 7 inches. There are three short branches. This canal was opened in 1760, and has a great trade in coal.

Proceeding northwards, we find a very extensive canal pass quite from the western shore to the middle of the kingdom, named the Leeds and Liverpool canal. It commences at Liverpool, and terminates in the Aire and Calder navigation at the tunnel at Leeds, a total distance of 130 miles. The rise from low water in the Mersey to the canal basin is 52 feet, and thence to the summit near Colne 431 feet. From the summit to the eastern termination the fall is 410 feet. The locks are for boats 70 feet long, with 14 feet beam; and the canal has 4½ feet of water. The great tunnel of Foulridge is 1630 yards in length; it is 18 feet high, and 17 feet wide. The purposes of this canal are to open a communication between Yorkshire and Liverpool, carriage of coal and lime from the neighbourhood of Wigan, &c. and the transport of agricultural produce. The acts are 10, 23, 30, 34 Geo. III. Engineers, James Brindley and Robert Whitworth.

At West Houghton, near Wigan, commences the Lancaster canal: it passes Chorley, Garstang, Lancaster, and Burton, and terminates at Kendal in Westmoreland, in all a distance of about 76 miles. Its detail is as follows: From West Houghton to Barkhill, 3¼ miles, it is level; thence past Chorley to Clayton Green, to near the south bank of the river Ribble, 13¼ miles, it is level. From Clayton Green, across the valley of the Ribble, to the top of its south bank, 3¼ miles, a fall of 222 feet, is passed by a railway and inclined plane on each side of the valley. From the north bank past Garstang and Lancaster to Tewitfield, near Borwick, 42¼ miles, is level; from thence to Kendal 14 miles, there is a rise of about 66 feet. Near to Lancaster there is a very fine aqueduct of 5 arches, each 70 feet span over the river Lune. See Plate CCCCXIV. Fig. 5. The canal is for boats of 14 feet beam. The acts are 32, 33, 36, 40 Geo. III. James Brindley was employed in this scheme in 1772. Robert Whitworth was employed in 1791, and John Rennie directed the execution of the works. The country adjacent to its southern extremity abounds in coal mines; and there are mountains of limestone near its northern termination. To connect these, and facilitate the general intercourse of that extensive district, are the purposes of this canal.

North of Lancaster, the country continues mountainous to near the borders of Scotland. But adjacent to Carlisle, in the county of Cumberland, the country is comparatively flat, and well cultivated; and from thence across the country to Newcastle there is a sort of valley, through which the rivers Irthing and Eden flow to the westward, and the Tyne to the eastward. The narrowness of the island at this place, and the comparative lowness of the summit, has frequently suggested the idea of a canal between the east and west seas, and to open the great mines of coal, lime, and lead, which are situated in the interior of the country. In 1795, a survey was made by William Chapman, and examined and approved by Mr. Jessop, and a bill brought into Parliament for a line of canal, commencing to the eastward of Newcastle, passing on the north side of that town, the river Tyne, and the town of Hexham, to a summit at Glenwhelt, 445 feet above the level of the sea; from thence descending westward down the southern side of the river Irthing, and town of Brampton; and after crossing the river Eden, and passing on the south side of the city of Carlisle, terminating in the Irish sea at the port of Workington, about 30 miles from the said city; the total distance being about 94 miles. The general utility of this canal was admitted; but owing chiefly to a difference of opinion as to which side of the valley of the Tyne the canal should pass, the bill was thrown out; and the measure has not since that time been generally resumed, although portions of it, as partial projects, have been occasionally taken up. The city of Carlisle having considerably extended its manufactures, and also increased in population, and being desirous of creating a competition in the supply of coals, and of opening a communication by sea-vessels quite up to the city, employed Thomas Telford in 1808 to make a survey and report of the best means of accomplishing this object. Finding that the Solway Frith was navigable by coasting vessels up to past Bowness, distant about 13 miles from Carlisle, he recommended a canal between these two places for small sea-vessels. The plan was approved of; but the state of the country being then unfavourable for new projects, it was only in 1818 that Mr. Chapman produced a plan and report upon this line from Bowness to Carlisle; upon which a bill was brought in, and an act of Parliament obtained early in 1819. Mr. Chapman's plan is for locks 74 feet long, 17 wide, and 8 feet depth of water in the canal. The canal terminates in a field on the south side of Carlisle, at 32 feet above the Solway basin. This, when executed, will form a portion of the general line across the island; and Mr. Telford having, in 1819, surveyed a continuation to the town of Brampton, it is hoped that Mr. Chapman will be enabled to carry on, and by degrees complete his very excellent line of communication across the kingdom.

On the eastern coast there are three rivers which deserve attention, from being navigable for some distance from their mouths, and the great intercourse in coal and lime which is carried on in two of them. The rivers we allude to are the Tees, the Wear, and the Tyne.

The Tees divides the counties of York and Durham, and the tide flows up it 12 miles to Stockton, to which place it is navigable; the spring tides rise about 13 feet. The imports are deal timber and general merchandise; and exports are agricultural produce.

The river Wear is navigable from its mouth past Sunderland, about 8 miles into the country, to the vicinity of Lumley Castle. The tide rises 13 feet at its mouth, which, although confined by peers, is incommoded by a bar. A very great trade is carried on here in coal and lime. The coal is sent chiefly to London and the south of England, the lime to the north of Scotland. From the staiths, or shipping platforms, on the banks of this river, various iron railways proceed to the works, distant about seven miles. From these staiths, on the steep banks of the river, the loaded waggons are discharged immediately into the vessels which lie below them. At Sunderland, the sea vessels pass under the great iron bridge, which is 236 feet span, and 100 feet high, without interruption.

The river Tyne which has, for many ages, been the principal sea-port for coals, is in its lower part the boundary between the counties of Durham and Northumberland. The towns of North and South Shields stand on each bank near its mouth, where the spring tides rise 13 feet. The river is navigable for large vessels 15 miles up to Newcastle. The coals are generally delivered to the coasting vessels by means of certain barges, known by the name of Keels, which by acts of 11 and 15 Geo. III. are to carry 8 Newcastle chaldrons, or 21⅕ tons. In many instances, however, the coals are brought by waggons on railways from the mines to the river, and from platforms and spouts on its banks shot immediately into the vessels. It is said that wooden railways have been in use ever since the year 1680.

The Humber.

The estuary called the Humber, has its mouth in the German Sea, about 5 miles in width. In passing 20 miles up to the town of Hull, it contracts to about one mile; thence westward it passes between the Lincolnshire and Yorkshire Chalk Wolds for about 18 miles, terminating in a marshy flat, which is the general receptacle of the rivers of the adjacent districts. Of these, two are chiefly remarkable, viz. the Trent southwards, and the Ouse towards the north-west, each following the hollow of the red land soil, and forming a natural navigation for upwards of a hundred miles, through this fertile part of England. On the west of this line is a coal country, extending, with little interruption, from the Newcastle fields as far south as Coventry. Behind which, Derbyshire affords limestone and lead, while gypsum and other minerals are found in the lower parts of the basin. The numerous flocks fed on the heights of Yorkshire had early created extensive woollen manufactures at Leeds, Halifax, Wakefield, &c. and they are still the seats of that trade. The abundant water-falls in Derbyshire induced the working in cotton, before the application of the steam engine was known. Nottingham and its vicinity was chiefly employed in hosiery and lace; and, in the southern parts of Yorkshire, Sheffield is the seat of an extensive cutlery trade. These important circumstances, with the necessity of embanking and draining the low lands, early promoted an extensive inland navigation, first by means of the natural streams, next by side-cuts, locks, and weirs; and lastly, by artificial canals.

Hull is the great sea-port of this district; its population being upwards of 30,000. It is provided with extensive wet docks, capable of admitting 50 gun ships. It carries on an important trade with the north of Europe.

In Lincolnshire, at the mouth of the Humber, is the Louth navigation. It commences at the town of Louth, and passes by Leatherhill Mead, Kiddington Old Mill, North Cockering to Titney; in all 14 miles, with a fall of 56½ feet.

At Grimsby, a cut of large dimensions has been made 1½ mile to the tideway. The sea lock is 126 feet long, 86 feet wide, with 20 feet water. Act 36 Geo. III. John Rennie, engineer.

In the northern parts of Lincolnshire, the Caistor and Ancholme navigations join the Humber above Hull. The Ancholme is 26 miles; act 42 Geo. III. The Caistor branch is 9 miles; act 35 Geo. III. The purposes of it are drainage, and supplying the towns of Caistor and Market Raisen.

North of the estuary, the river Hull passes from the sea-port of Kingston upon Hull to Beverley. About 12 miles thence the Duffield canal, by acts 7, 41 Geo. III. continues N. 11 miles to Great Duffield. The first 5 miles is by the river, the remainder by a canal. Engineer, John Smeaton. A branch from it is the Hull and Leven canal, 3 miles. Acts 41, 45 Geo. III.

Near the upper end of the estuary, opposite the Trent, is the Market Weighton canal. It passes nearly north about 11 miles. A sea lock at its mouth communicates with the Humber; thence it is level to near its head, where there are 3 locks. Acts 12 Geo. III. Engineer, John Smeaton.

We now proceed to the northern great branch of the Humber, the river Ouse. From the Trent this river is navigable 15 miles, for vessels of 150 tons, to Armin, at the junction of the Aire and Calder navigation. From thence it has a crooked course of 25 miles to the city of York. In this space it receives at Barnaby the river Derwent, navigable about 35 miles to New Malton; and near York the Foss navigation, 33 and 41 Geo. III. proceeds northward 13 miles to Stillington Mill.

On the south side the Ouse receives the river Dun at Goole, and the Aire and Calder at Armin, and also by a canal at Selby, (as will be afterwards described.) At Cawood it receives the Wharfe, having a bad navigation of about 9 miles to Tadcaster. Between Cawood and York there is one lock.

Above York, the Ouse, or Yore river (act 7 Geo. III.) continues navigable for 20 miles to Aldborough, where it receives the Swale, and where, also, the Rippon canal commences, and proceeds partly by the river, and partly by canal, to the town of Rippon. At Linton is a lock and weir, and the fall above it is one inch per mile. John Smeaton was the engineer. There are other locks at Borough Bridge, &c. The Swale river is navigable by weirs to Topcliffe Mills. In 1801, a canal was proposed from Topcliffe to the river Tees, for the purpose of conveying coals from the county of Durham into the north parts of Yorkshire.

Returning to the mouth of the river Aire, which, with its branch, the Calder, forms the most direct and important navigation into the coal and great manufacturing districts in the West Riding of Yorkshire, not less than three canals, besides numerous branches, have been carried from this river across the central ridge of England, to the towns of Manchester and Liverpool, thereby converting it into one of the two great channels of water communication across the kingdom, between the ports of Liverpool and Hull.

The Aire and Calder navigation, though proposed in the time of Charles I. was incorporated under act 10 and 11 William III. being undertaken, it is said, by a Dutch company, who, after expending about £19,000, were ruined by the enterprise. Their property was purchased, and the works resumed by the corporation of Leeds, and some gentlemen of Wakefield; and by the subsequent extension of navigation, it has become very profitable. The second act was obtained 14th Geo. III. (1774.)

The river Aire, from the Ouse at Armin, is ascended by 50 or 60 ton sloops, for about 40 miles, to the town of Leeds, where the Leeds and Liverpool canal commences, as has already been described.

About 10 miles below Leeds, the river Calder branches off to the south-west, and is navigable about 10 miles to Wakefield.

Here the Calder and Hebble navigation commences, and proceeds partly by the river, and partly by side cuts, and locks and weirs, 23 miles to Sowerby Bridge, near Halifax, where the Rochdale canal commences, and passing the central ridge at the north end of Blackstone Edge, proceeds to Manchester, as already described.

The third navigable communication across the summit, the Huddersfield canal, branches also from this navigation at Cooper's Bridge, near the junction of the Colne river, by Sir John Ramsden's canal, to Huddersfield, and from thence the Huddersfield canal, as has already been described, passes by a great lockage, and a tunnel of three miles, across the Saddleworth range of hills, and finally to Manchester, by the Oldham canal. By the second act, (14 Geo. III.) power was given to make a canal from the Ouse at Selby, to the Aire at Haddlesey. At Selby there is a tide lock, and seven more between that and Wakefield. The distance from Selby to the junction of the rivers, is $20\frac{1}{2}$ miles, thence to Wakefield 10; and to Leeds 8 miles.

The Calder and Hebble act passed about 1757. The length from Wakefield to Sowerby Bridge, is about 23 miles. In this distance there are 15 side cuts of various lengths, from 200 yards to 2 miles. The whole rise from Wakefield is 178 feet, by 26 locks—each about 66 feet long, and $14\frac{1}{2}$ wide. Great improvements have been made under the present very deserving engineer, Mr. Bradley.

Below Wakefield, the Aire and Calder company have widened their locks to 18 feet; but should any vessels be built to suit these locks, they must navigate by way of Armin, as the tide lock at Selby is only $14\frac{1}{2}$ feet wide.

The boats used in these navigations are 56 feet long, $13\frac{1}{2}$ wide, draw 3 feet water, and carry about 28 tons. They usually go double, make way about from 2 to $2\frac{1}{2}$ miles per hour. They are often taken down the Humber, and round the coast to the Welland and Great Ouse rivers.

The branches from the Aire and Calder navigations are numerous. Near Snaith it connects with the Dun river. Higher up is a cut to the Ouse at Selby, to shorten the distance to York. At Wakefield, the Calder and Hebble connects with the Barnsley canal, (act 33 Geo. III.) and there are many rail-way branches to coalworks.

The Barnsley canal proceeds about south $11\frac{1}{4}$ miles to near Barnsley; then westward $4\frac{1}{4}$ miles, as a continuation of the Dearne and Dove canal. At Eym is an aqueduct of five arches, over the Dearne river. From the Calder, in the first three miles, the rise is 120 feet by 21 locks, partly fed by a reservoir near Old Himley, and partly pumping back the water by a steam engine. This canal is for the export of coal, also flag-stone for pavements, and to connect the manufacturing towns in the West Riding of Yorkshire. Engineers, William Jessop and William Wright.

From this last canal proceeds the Dearne and Dove canal, (acts 33 and 40 Geo. III.) It unites with the Don navigation near Mexborough, and is calculated for the same kind of boats, carrying about 50 tons. Commencing at the Don, it proceeds to Knollbrook, $4\frac{1}{4}$ miles, rise $41\frac{1}{4}$ feet; thence to Oldham Mill $2\frac{1}{8}$ miles, rise 24 feet; then to the Barnsley canal $2\frac{7}{8}$ miles, rise $53\frac{2}{3}$ feet. The locks are 67 feet long, by $15\frac{1}{2}$ wide. It was finished in 1804. Engineer, John Thompson.

The Don or Dun river (act 12 Geo. I.) empowers the company of cutlers in Hullamshire to make the river Dun navigable from Holmstile, near Doncaster, to Tindly, a township about $3\frac{1}{2}$ miles from Sheffield. By 13 Geo.

I. the corporation of Doncaster is empowered to improve the navigation the Don, (which had previously only been navigable for small boats up to Doncaster, a part of the year,) from Holmcastle down to Wilock, parish of Barmby upon Dun. The 6th Geo. II. united both into one company. The 13th Geo. II. was for farther improvements. The total length of the navigation is 31½ miles, seven of which consist of short cuts. About nines miles below Fishlake Ferry, the river Dun joins the Ouse, at Goole. The navigation does not appear to have been completed before 1753. There are 18 locks, rising 70 feet. Length of locks 63 to 72 feet; breadth 15¼ to 18 feet. Length of vessels 56 feet, breadth 15 feet.

The trade consists in coal, lime, iron and earthen wares, groceries, corn. It supplies Sheffield, Doncaster, Rotherham, &c.

From the lower part of the river Don, the Stainforth and Keadby canal (acts 33 and 38 Geo. III.) proceeds 15 miles to the Trent. It has a tide lock at each extremity; and is chiefly for drainage.

The Trent river forms a very extensive navigation, and its importance is much increased by the various branches and artificial canals which connect with it. By the Trent and Mersey, or Grand Trunk Canal, it is united to the river Mersey, and to the Severn; and of late by the Soar river, the Leicester, the Union and Grand Junction canals, it communicates with the river Thames. The Foss navigation, one of the most ancient in England, had early connected it with the river Witham, and port of Boston, and a variety of branches, upon the rich country on each side. The tide flows up this river as far as Gainsborough, which is navigated by coasting vessels. The channel of the river is through the fens, and is embanked on both sides. In this space at Keadby, is the Stainforth and Keadby. At Stockwith, the Idle navigation, and also the Chesterfield canal, depart to the westward. Above Gainsborough, the channel is frequently obstructed by shallows; so that, in 1761, the navigation, as reported by Mr. Smeaton, could only be maintained by flashing from the mills. By the 34 Geo. III. a side-cut of 10 miles was made, to avoid two bridges and sandy shoals, which occur in 13 miles in the upper part of the river. This cut is sometimes called the Trent canal. It commences at Trent Bridge, near Nottingham; has a rise of 28 feet, and connects with the Erewash canal near Lawley, and has a short cut and a lock into the Trent in Beeston, and terminates at Lawley Ferry, in the commencement of the Trent and Mersey canal. The above act (34 Geo. III.) also embraces the general improvement of the river, the formation of horse towing-paths, &c.

In this space the Trent receives, on the eastern side, the Foss navigation from Lincoln, the Grantham canal, and the river Soar navigation; and, on the west, the Nottingham canal, the Erewash canal, and the Trent and Mersey canal, with their various branches.

At Stockwith is the Idle river, navigable 10 miles through a fen country to the town of Bawtry. At Misterton is a lock 17⅔ feet wide, with doors 16 feet high, built on the site of the old Dutch lock, by John Smeaton.

Above the junction of the Trent and Mersey canal, the river Trent navigation is the property of the marquis of Anglesea, under acts 10 and 11 William III. and proceeds in a crooked course for about 19 miles to Burton on Trent, making the whole river navigation about 135 miles. At Swarkstone it receives the Derby canal.

Leaving the farther progress of the Trent navigation for the central district, we return to the branches of the river, whether they are canal or river navigations.

Near the mouth of the Idle river is the junction of the Chesterfield canal, act 10 Geo. III. Commencing in the river Trent, it passes by a crooked line of 46 miles to Chesterfield, on the river Rother.

To Worksop, 24 miles, the rise . .	250 feet.
Norwood, 9 do. do. . .	85 do.
Total height, ...	335 feet.

At this level there is a tunnel 2850 yards in length, width 9 feet 3 inches, height 12 feet; and there is another tunnel, 153 yards in length, at Drake's Hole. From Norwood to Chesterfield, 13 miles, the fall is 45 feet.

To Retford this canal admits barges of 60 tons; above that, it is only for boats of 7 feet beam, and 70 feet long. The tunnel was begun in 1771, and completed in 1775. The engineers were James Brindley and John Henshall. The exports are coal and lead, and the imports deal baulk, corn, groceries, &c.

The Nottingham canal, completed in 1802, proceeds from the Trent, and passing that town, has a winding line for about 15 miles, to the junction of the Erewash and Cromford canals, at Langley bridge. The rise is 108 feet, it is supplied by a reservoir at Ainsworth. The engineer was William Jessop. The exports are coal, lime, lead, and the imports, merchandise for Nottingham, &c.

The Cromford canal proceeds from the head of this last, 18 miles past Hynor Harly, Tadmoor and Critch, to Cromford near Matlock. In the first four miles there is a rise of 80 feet—the rest is level. It is made through a very rugged country, and has several tunnels, one at Ripley of 2966 yards in length, and 9 feet in width. It crosses the Derwent by an aqueduct 200 yards long, and 30 feet high. There is one canal branch of three miles from it, and two railways to the several adjacent works. Exports, coal, lime, lead. Imports, general merchandise. Engineer, William Jessop. Completed in 1794.

From the junction of the Cromford and Nottingham at Langley bridge, the Erewash canal (act 17 Geo. III.) proceeds to the Trent near Sawley ferry, and opposite the mouth of the Soar, or Loughborough navigation, being a distance of 11¾ miles, with a fall of 108 feet. There is a railway branch to Brinsley coalworks. Near the middle of the length, the Nutbrook canal joins. Farther down is a branch of the Derby canal, and near Sawley, the Trent canal. Trade nearly the same as in the Cromford canal. William Jessop, engineer.

The Nutbrook canal, act 33 Geo. III. is a branch from the western side of the Erewash. It proceeds north-west 5 miles to Shipley colliery. It also has a branch to West Hallam collieries.

The Derby canal commences in the Trent at Swarkstone bridge, whence, to the Trent and Mersey canal, is a rise of 26 feet in half a mile; thence to Derby 5¼ miles, rise 12 feet. It here crosses the river Derwent by means of a tumbling bay, and proceeds 3¼ miles to Little Eaton, rising 17 feet. From the eastern bank of the Derwent, a branch proceeds 8½ miles to the Erewash canal, with a fall of 29 feet. This canal is for boats of 14 feet beam. Act 33 Geo. III. Engineer, Benjamin Outram. There are railways from this canal to Horseley collieries, to Smithy Houses, near Derby, 4 miles; to Smolley Mills, 1½ mile. The exports are coal, lime, iron.

On the opposite side of the Trent we have various navigations, as formerly noticed. The Fossdyke navigation from the Trent to the Witham at Lincoln, begun probably by the Romans, was materially enlarged and improved in 1121 under Henry I. but the description of it belongs to the Fen district.

At Newark the Dean river has been improved under the 12 Geo. III. for two miles to the town of Newark. It was completed in 1797.

The Grantham canal (acts 33 and 39 Geo. III.) commences at the river Trent, nearly opposite to the mouth of the Nottingham canal. It proceeds up the Vale of Belvoir, by a crooked course, 33 miles to Grantham. Total rise 141 feet. There is a level branch of 3½ miles to the town of Bingham. The Grantham canal is fed entirely by reservoirs, which collect the flood waters. The imports are coal, lime, deal baulk, &c. and the exports agricultural produce.

The river Soar, or Loughborough navigation, falls into the Trent nearly opposite to the Erewash canal. Act 16 Geo. III. It follows the course of the river Soar for 9 miles to near Loughborough, where a cut of one mile continues it to that town. Here it connects with the Leicester navigation, and also the Charnwood Forest Railway, which proceeds westward 2½ miles, with a rise of 185 feet to the Forest Lime Basin, where commences the Charnwood Forest water-level of 8¾ miles, with a branch three quarters of a mile to Thringston Bridge. There are branches of railways to the lime works of Coal Orton, Barrowhill, and Cloudshill, also Swannington collieries. From the Cloudshill lime works, the railway is continued 6½ miles to the Ashby de la Zouch Canal.

The main line of the Leicester navigation (acts 31, 34, and 37 Geo. III.) commencing in the Loughborough Basin, proceeds on one level three miles to the separation of the Melton-Moubray line. From thence to Leicester the distance is 11 miles, and rise 45 feet. Engineers, William Jessop and C. Stavely.

The Melton-Moubray line (acts 31 and 40 Geo. III.) leaves the last at Turn Water Meadow, 3 miles above Loughborough, following the course of the Wreak and Eye rivers, 12 miles to the town of Melton-Moubray, where the Oakham canal commences.

The Oakham canal (acts 33 and 40 Geo. III.) ascends by a winding course about 15 miles to the general summit between the Trent and the Fen Basins, at the town of Oakham, viz. to Edmondthorpe, 8½ miles, rise of 26 feet; thence 6½ miles to Oakham level. It is supplied by reservoirs. Engineers, William Jessop and C. Stavely. It was opened in 1803. The imports are coal, lime, deal baulk, merchandise.

From Leicester the Union Canal proceeds to Market Harborough, and from thence by the Grand Union to the Grand Junction Canal, and completes the connection to London and the Thames from this part of the Trent river; but this last canal belongs to the Central District.

Although an inland navigation has been opened from the vallies of the Trent and the Soar to the summit of the country at Oakham, and although an extension of 15 miles, down to Stamford, would connect it with the Welland, which falls into the Wash Bay, yet all attempts at accomplishing this have hitherto proved abortive. In 1810, Thomas Telford surveyed the country, and made a plan for extending the communication to the Welland at Stamford, the Witham at Boston, and the Nene at Peterborough, thereby embracing the whole bay of the Wash. A sum equal to the estimated expense was subscribed, and a bill brought into parliament; but, from various causes, it was opposed and defeated.

Fen District.

The great level district of the Fens forms a strongly marked division of our subject. The high ground which forms the boundary of the extensive flats which surround the bay called the Wash, to the eastward in Norfolk and Suffolk, and also in the Wolds of Lincoln, composed of chalk, and the inlet of the Wash itself, seems to occupy a great breach of this chalk range. To the westward, the upper grounds are of a different nature, being chiefly the freestones, or oolites, which occupy a considerably lower place in the series of strata. It may therefore be naturally concluded, that the bottom of the great level consists of the sands and golts, or marls, which occur in the intermediate space between these rocks when found in supra position; and which sands and marls spread over a flat surface, will readily account to us for the obstructed drainage, and vast accumulation of peat bog, or moor, which distinguishes this portion of our island.

Those parts within the reach of the spring tides would first be covered with the deposition, or warp, from the sea, and be converted into rich salt marshes, and which, by the regular flux and reflux of the tides, would enjoy the most effectual drainage. The securing of these would naturally attract the first attention of an industrious people; hence the early embankments of Holland and Marshlands, supposed to have been the work of the Romans: but this embankment became, in its turn, the main cause of the inundation of the great Fen behind. The greater floods had not their former direct passage to the sea, but were confined to certain reservoirs, or creeks only, and, regaining a head, penned up the land waters in the inner parts of the flats. The growth of aquatic vegetables succeeds, and promotes the stagnation. The depositions both from the land and sea take place, and injure the outfalls, which go gradually to decay. In process of time the bed of the ancient outlet becomes higher than the adjacent country, and obliges the upland waters to find a new and more circuitous outlet to the sea. This process, of which we have abundant instances in all countries of similar formation, is strongly exemplified in the outfalls of the bay of the Wash, while the numerous cuts which have been made, very questionable even as regards drainage, prove undeniably injurious to the navigation of the original rivers. But it is equally certain that inland navigation generally has thereby been greatly extended; because, as these cuts and drains are chiefly embanked, and nearly still water, they form navigations, ramifying and crossing each other in so many directions, as to render it vain for us here to particularize them all.

The Ouse is the chief river of this district. Its outlet was formerly by Wisbeach, then a very considerable seaport. Between Wisbeach and Erith the river had two channels, viz. one on each side of the island of Ely.

Of these, the Eastern, or Old Ouse ran by Ely to Littleport. Having received the Grant from Cambridge, and the Mildenhall river from Littleport, it passed to Wisbeach, instead of uniting, as at present, with the Lesser Ouse, and passing to Lynn. The other branch, called the Westwater, passed from Erith to Ramsay Mere and Benwick, where it met part of the Nen, then by Great Cross, to meet the other branch at Wisbeach, and so out to the sea.

The most remarkable change on this river, was the cut from Littleport into the Rumden river at Rebeck. Not only the original eastern, or Ely branch, was conveyed to the sea at Lynn; but even much of the Westwater and river Nen, and even part of the Welland, instead of passing to Wisbeach, ran by the Welle river to the same new cut at Littleport. It would also appear by the petition from Marshland, in the reign of Edward III. that the lower part of the united Western Ouse and Nen, called the river Welle, had, at the suit of the inhabitants of the upper counties, been diverted from the original outlet at Walsoken, near Wisbeach, and carried along the Marshland to the Ouse at Wiggenhale. While, therefore the outlets towards Wisbeach were rapidly silted up, nearly the whole waters of the Fen were conveyed to the haven of Lynn; which, from this cause and the increased flux and reflux of the sea, became greatly deepened and enlarged. Strenuous efforts were made by the people of Marshland to have the Ouse narrowed, and confined between banks, as formerly; but they were constantly opposed by those of Lynn.

The next remarkable alteration on the Ouse was Popham's Eau, from Upwall to Denver. Its object was to take off the Welle stream by a shorter course than that at Littleport, and more open and direct than the old channel through Welle. But Bedford river, and the New Bedford, or Hundred-foot river, parallel to it, forming a direct channel of 20 miles through the Fens, from Erith to Denver, was by far the greatest change to which the course of the Ouse was subjected, and, in the end, has laid dry all the upper part of the Westwater.

Above the Fen country the Ouse river continues navigable to Bedford, about 84 miles from the sea. Its various branches will be described hereafter.

The next river in importance and order is the Nen, navigable from the sea below Wisbeach through the Fens to Peterborough, and thence by the regular channel, improved by side cuts and locks to Northampton. Below Peterborough the river seems to have spread into various lakes, as Wettlesey Mere, Ramsay Mere, &c. ere it joined the western branch of the Ouse at Benwick, as afore mentioned, and passed therewith to Wisbeach, as to the Ouse at Salter's Lode by the river of Welle, &c. Various attempts have been made to shorten the course of the Nen: Of these, the Catwater, on the northern side, was an ancient cut to the triangular bridge at Crayland, to unite with the Welland, and pass by Spalding; but that outfall decaying, the Catwater became useless; and, somewhat lower down, the waters of the Welland were brought by the South Eau to Guyhirn, and thence back to the channel of the Nen and Wisbeach, or even by the Welle to the Ouse.

To the south, King's Delf and Whittley Dyke are ancient cuts to shorten this river; but the most important is Morton's Leam, from Peterborough to Guyhirn and Wisbeach, first opened by Moreton, bishop of Peterborough, in the reign of Henry VII.; since perfected by Charles I. jointly with the Bedford level adventurers. This also drains off the waters of the Welland.

The river Welland having entered the Fens at Deeping, passed originally to Crayland Bridge, and by Spalding to Sarfleet, where, receiving the river Glen, it proceeds to the sea at the Foss-dike Wash. This river seems to have been chiefly injured by the injudicious modes employed to drain the adjacent Fens, thereby abstracting a great proportion of its waters. A variety of plans have been suggested for changing the course of the Welland, and relieving the district of South Holland, viz. instead of allowing its waters to pass to the Ouse, to conduct them along the north shore to the Witham; and, in 1751, Kinderby proposed to carry both the Nen and Witham nearly as far east as Wainsfleet.

But to understand the Fen navigations, we must enter at some length into the history of drainage in these very important and interesting tracts of country.

Until the latter end of the reign of Elizabeth, the business of drainage generally was entrusted to local Commissioners of Sewers, regulated partly by the custom of Romney Marsh, and partly by local temporary statutes. Their object chiefly was to preserve ancient channels and banks. No great work could be properly undertaken under their authority; these had hitherto been chiefly performed by religious houses; and on their dissolution by Henry VIII. it is probable many fell into decay. But about this time, officers, who, during their military service in the Low Countries, had observed the benefits derived from embanking and draining, introduced a new mode of proceeding, by professing to undertake the recovery of extensive tracts of land, on a regular plan, as a profitable adventure.

Captain Thomas Lovell, who undertook the drainage of Deeping Fen, is represented in the petition from Deeping and the neighbouring towns, 41st Elizabeth, as a man skilful in like works, wherein he had, beyond the seas, been much used and employed. He was to have completed the undertaking in five years, and receive one-third of the Fens. He however failed, and the Earl of Exeter and others succeeded to and prosecuted his work, making a tunnel for passing the water under the bed of the Welland, and thence by West Lode and South Holland to the sea: but the drainage after all seemed imperfect, and during the civil wars the works fell into decay.

Notwithstanding the feebleness of this attempt, it appears to have been the commencement of the grand project for draining all the Fens. In 43d Elizabeth, a general act was passed for recovering many thousand acres of marshes, and other grounds subject to commonty, within the isle of Ely, and the counties of Cambridge, Huntingdon, Northampton, Lincoln, Norfolk, Suffolk, Essex, Kent, and the county palatine of Duresme. In this act, it was stated that the chief obstacle to the recovery of such grounds, by skilful undertakers, is, that the greatest part of them are wastes and commons. A power was given to the owners and majority of commoners, to make contracts with the undertakers, and to convey to them a part of such lands (except crown lands without the royal assent) as might be agreed on by way of reimbursement.

Soon after the accession of James, this business was taken up with much earnestness. The king agreed that the crown lands should also contribute as the others, and appointed Henry Totnall and John Hunt to inspect and treat with the parties interested. Mr. Richard Atkins was employed to bore over the Fens to the depth of 11 feet. The general drainage was reputed feasible, and various water-courses, the great features of his plan, were explained by Mr. Hunt, the artist for drainage, viz. the formation of a new channel for the Nene, from March to near its junction with the Ouse at Salter's Lode, and another direct channel for the Ouse from Erith to near the same place, where the Ouse, at low water, was found to be ten feet below the soil of the Fen. These have since been nearly executed: The first called Popham Eau, the last the Bedford River. Sluices were also proposed by him at the two branches of the Ouse, at the head of the new cut.

By a survey by W. Hayward, the contents of the Fens proposed to be drained appeared to be 307,242 acres. On the 13th July 1605, Sir John Popham, Lord Chief Justice; Sir Robert Fleming, Chief Baron of the Exchequer; Sir William Romney, alderman; and John Eldred, citizen and clothworker of London, were declared undertakers of the drainage of all the Fens between Ouse and Deeping, and were to have 130,000 acres for their portion.

On the 5th August 1605, Hunt and Atkins laid out Popham Eau, which was opened 21st December, to Upwell; but in the following March it broke its banks, and had to be stopped. In 1606, a bill was brought in to regulate the drainage, which proceeded but slowly. In 1609 Popham Eau was enlarged. In 1611 a channel was laid out and made by Hunt, for the drainage of Ouldham and Watersey, being a separate undertaking. In 1613, a very high tide broke the dykes of Marshland, and did damage to the amount of 40,000*l.* Various efforts were made, but little effectual progress was made in any essential improvement, during the remainder of this reign: but in the early part of Charles I. the business of drainage was again resumed. Artists were brought from Holland. Cornelius Vermuyden's first work in England was the embankment of Dagenham marshes, for which he had a part of the lands assigned to him, and confirmed by patent in 1621. In 1626 he undertook the drainage of the Fens in Hatfield Chase, between the Trent and Ouse, and effected the same in five years, at an expense of 55,825*l.* for which he had one-third of the lands assigned to him. In the same year, 1626, he proposed a plan for draining the great level, upon 95,000 acres being assigned to him; but this was objected to, on account of his being an alien. Francis, Earl of Bedford, with various other adventurers, undertook the works on the same terms, and were incorporated by 10th Charles I. in 1633. (See Dugdale.) The works performed by this company were as follow:

1. The Old Bedford River, 21 miles, 70 feet wide, with a sluice at each end, as a slaker to the Ouse.
2. Same cut, 10 miles, 20 feet wide, from Feltwell to the Ouse.
3. Mildenhall cut, two miles, 40 feet wide.
4. Bevil's Leam, 10 miles, 40 feet wide, from Wittlesley Mere.
5. Morton's Leam renewed.
6. Peacock Drain, 10 miles, 17 feet.
7. Hill's cut, two miles, 50 feet, near Peterborough.
8. New South Eau, from Crowland to Clow's Cross.
9. Shire Drain, opened at Clow's Cross to Tyd and the sea, with a sluice at each end, being a slaker to the Welland; projected in the reign of Elizabeth, and perfected by these adventurers.

Locks for navigation, or Sasses, were built on the Well Creek, and at the Horse Shoe, below Wisbeach.

These works were executed in about three years, at an expense of about 100,000*l.*; but it was found, that although the country was greatly relieved, it was still liable to inundation during winter floods; and 40,000 acres only were allotted to the adventurers. In 1638, the king took on himself to perfect the drainage, both of the Deeping Fen and the Great Level; and having procured reports on the subject, chiefly from Sir Cornelius Vermuyden, a system was devised, with broad wakes on the sides of the principal drains, to contain and take off the flood waters; and the king was to have half the portion of the former adventurers, and an additional 5000 acres, for the Bedford Level 12,000, and 3000 acres for the other marshes and fens in Holland and Marshland.

The works executed under this agreement were, 1st, The south bank and part of the north of Morton's Leam; a new cut, 2½ miles below Horse Shoe Sluice, at Wisbeach; a new outfall sluice for Shire Drain, soon afterwards swallowed up by the quicksands; and a navigable sas, at Stanground on the Nene. All further progress was stopped by the civil wars.

In 1649, the claims of the adventurers were revived by William, Earl of Bedford; and having obtained their original contract, the works were completed in 1658. This company constructed banks along the river Welland, Morton's Leam, the Bedford River, the river Ouse and its branches. They also made the following cuts:

1. The New Bedford River, parallel to the old one, of 100 feet in breadth.
2. Vermuyden's Drain, from the river Nene at Ramsay, to the Old Bedford River.
3. Monkland cut and Dounham Eau, between Denver and Stowbridge.
4. Stoney Drain, and a variety of smaller works, besides clearing and repairing the old outfalls.

They also placed sluices for navigation at Hermitage, near Erith, to direct the water by the new channel; and at Denver, near the outfall of the said channel, to prevent the regurgitation of flood waters up the old Ouse. The silt brought down by the greater slope of the new channel soon raised the bed of the Ouse at Denver sluice several feet, to the great injury of the navigation and drainage of that river. That sluice having been blown up in 1713, its re-establishment was opposed by the town of Lynn and other places, so that it was not rebuilt until 1746. Since which time, the most remarkable alteration in the wake of the Great Level has been the Eaubrink cut of 2¾ miles, to straighten the course of the river above the town of Lynn. This cut was recommended in 1725 and 1751, by Badeslade and Kinderby, and has since been executed under acts 35th, 36th, 45th, and 59th Geo. III. Robert Mylne, Sir Thomas Hyde Page, and Joseph Huddart, being the engineers first employed, and at present John Rennie and Thomas Telford.

The navigations within the Fens are the property of, and supported by the Fen company. They have likewise occupied various works upon the other outfall, particularly a new channel for the Nene, from Wisbeach to the sea.

The districts of South Holland and Marshland drain immediately to the sea by various small cuts; and Deeping Fen by tunnels under the Welland. Though this bold measure effected the draining of Deeping Fen, it operated seriously to the injury of the outfall of the river Welland below Spalding; so that the waters of that river were constrained to pass towards the Nene and Ouse, thereby injuring a country much more extensive than that which had been benefited; and in 1613, Sir Clement

Edmonds and the commissioners were obliged to have their boats carried by carts three or four miles to Fossdike, where great ships lay at anchor, for want of a current to carry them down the channel. During the civil wars, the banks, &c. became ruinous, and in Dugdale's time the level was overflowed. The drainage was restored by a new company under act 16th and 17th Charles II. and a new cut of four miles in length made from Spalding to the reservoir at the mouth of the Glen river; and the lower part of the river being contracted, the navigation to Spalding was much improved; and in 1794, an act was obtained for a cut from Spalding to the mouth of the Witham at Wyberton Roads, but which has not been executed.

The drainage of South Holland and Lindsey Level, towards the Witham, instead of Welland or Glen, had been an early project. In 34th Henry VIII. Charles Duke of Suffolk, and others, Commissioners of Sewers, ordered a great sewer to be made along the bounds of Kistovan and Holland, to Langrake on the Witham, with four new sluices of freestone, each eight feet wide, at Langrake, by which we may perceive that the use of locks was not then known in England. The same scheme was renewed 17th Elizabeth, and a tax proposed for the purpose; but nothing useful was effected until 2d Charles I. when Robert, Earl of Lindsey, and others, proposed to undertake the drainage, on condition of having 20,000 acres of the land recovered. The drainage from Keyme Eau to Glen was effected by 14th Charles I.; but during the civil wars the country people took violent possession, and it was only accomplished by an act 5th George III. which authorized opening the South forty foot drain, from the Black Sluice at Boston to Hale; and thence a new and main drain of 40 feet wide and 6 feet deep, southwards to Guthrem, below Bourne on the Glen; also the repairing the old and new Hammond Becks. And in 1770 an act was passed for making these cuts navigable by locks.

In 1720, Earl Fitzwilliam cut the North forty foot drain, to drain his lands on the north of the Kyme Eau. The outfall of the Witham is supposed to be thereby much injured.

The Fens on the north of the Witham appear to have been originally drained towards Wainfleet, and the north Gouts above Boston. By 6th Charles I. the general drainage of that tract was undertaken by Sir Anthony Thomas, and others, for an allotment of land, and excepting various deep pools, it was effected in 1634.

From 1731 to 1751, the channel of the Witham had been so greatly injured, that the town of Boston was hardly accessible to vessels of 30 tons, and the navigation above that was entirely lost. After obtaining the opinion of various engineers, it was resolved to erect a grand sluice at the town of Boston, and to excavate a new river channel above that as far as Lincoln. Acts of parliament were obtained in 1761, and the work proceeded with. In 1766 the sea sluice was opened. Langley Edwards was engineer. The channel was in a short time greatly improved. Vessels drawing six to eight feet of water pass freely up to the town at neaps, and springs flow at the town from 12 to 15 feet. It is, however, very doubtful whether or not this improvement be attributable to the sluice.

The improvement of the channel below Boston next suggested the means of obtaining a better drainage for the adjacent Fens; and in 1812, the plan of Mr. Rennie was carried into effect, for conveying the outfall of the Fens to a lower part of the Witham, and taking off the upper waters by a general catchwater drain round the Fen, upon a higher level.

In regard to the ultimate benefit to the navigation of the Wash, by the alteration of the course of the Welland, we must refer to the judicious observations of Mr. Chapman, an intelligent merchant of Boston, who has published some pamphlets expressly upon this important subject.

In this quarter we must not omit noticing the Car Dyke, which skirts the uplands from the river Nene at Peterborough, to the Welland near Market Deeping, and from thence by Bourne and Billingham to the river Witham near Lincoln. It is a very ancient work, probably Roman. Its position leads us to think it has been a catch-water drain, but it might also be used for the purpose of navigating through this great extent of country. The portion between the rivers Nene and Welland was found, by Mr. Telford's survey of that country, to be very nearly level; and, to preserve this, the line is very crooked, and is, in one instance, cut deep through a rib of land. To the north of the Welland the line is more direct, and it has a gentle declivity to the river Glen, and other natural streams which intersect the country.

The great drains which have been made of late years are all navigable. The South Forty Foot is an excellent canal, being about 40 feet wide at the surface of the water: the length of it is about 21 miles.

The Foss Dyke canal, supposed to have been originally made by the Romans, and restored under Henry I. is connected with the Witham at Lincoln. At Braybrook Mere it proceeds on one level 11 miles, to the bank of the river Trent at Forksay, about eight miles above Gainsborough. It is preserved at the same level by a lock, having gates pointing in both directions. This is the oldest artificial canal in England; but we are uncertain in what manner it was anciently connected with the Trent, or even that it ever did form such a connection. In 1762, John Smeaton and John Grandy examined, and reported both with regard to the navigation and drainage. In 1782 Mr. Smeaton was again employed; and to his Reports, vol. i. we must refer for particulars, observing only, that he found merely 2 feet 8 inches of water in this canal; that he recommended raising the banks, cutting off any immediate communication with Braybrook Mere; constructing a lock at the Lincoln Summit; removing the natural ford called Braybrook-head; and gaining 10 inches more water in the canal. In 1782, Mr. Smeaton found reason to change some parts of his plan; but the general objects and effects were the same. The navigation has since been perfected, and the trade of the town of Lincoln is chiefly carried on by means of it.

From the Foss Dyke, at Lincoln, the river Witham proceeds south-east about 40 miles, past the town of Boston to the sea. In 1762, John Smeaton, John Grandy, and Langley Edwards, reported on the means of improving this navigation, which had been ruined by imprudent drainage. They recommended the construction of a sea sluice at Boston to exclude the tide water, having two pair of gates pointing to the land, and one pair to the sea; the other gates of the sluice to be so regulated as to preserve the water within two feet of the surface of the Fens; and above this sluice to open a direct channel, 80 feet wide at the top, 50 at the bottom, and 10 feet deep, with three pound locks, furnished with flood gates, to continue the navigation to Lincoln. The river is embanked on both sides to within 13 miles of Lincoln; in the remaining part the banks are level with the natural surface of the Fens, which are frequently overflowed.

From the north bank of the Witham, at Tattersal, proceeds the Horncastle navigation, (acts 32d and 40th George III.) opened in 1802. It commences in the Old Witham; follows the old cut to Tattersal, then by the course of the Bain River to Horncastle. Its length is 11 miles.

From the south bank of the Witham, at Chapel Hill, the Sleaford navigation proceeds 12 miles, in a southwest direction, to Sleaford, being embanked most of its course through fens. It is 30 feet at top water, 18 at bottom, and five feet deep. The locks are 60 feet long and 15 feet wide. Above Spalding, to which, as has already been observed, the river Welland is accessible by the present channel, the navigation proceeds by an artificial channel through the Fens to Market Deeping, and from thence by sundry side cuts, locks, and weirs, to the town of Stamford. This is one of the oldest works of this kind in the kingdom, viz. 17th James I. The works have been originally ill-planned, and are now in a ruinous state. Mr. Telford's scheme for the Stamford navigation included the improvement of this as far down at St. James's lock, below Market Deeping. The fall from Stamford to the third lock is only 7 feet in the distance of 3 miles and 306 yards. From thence to the top of St. James's lock the distance is 6 miles 655 yards, with a fall of 44 feet. The present locks are 12 in number, admitting vessels of 7 feet beam, and carrying only 15 tons.

By the South Eau and Cat Water, a navigation is formed from the Welland at Crowland, in two directions, to the river Nene, and also to the sea by Gunthorpe sluice.

From the bay of the Wash, at Peter's Point, the river Nene proceeds about 9 miles to the town of Wisbeach, and thence by two or three different embanked channels through the fens to Peterborough, being about 40 miles, near which the lock of Stoneground sluice was early constructed, partly for navigation, and partly to direct the flood waters through Morton's Leam.

From Peterborough, the original channel has been improved by side cuts, locks, and weirs, under acts Geo. II. and 34 Geo. III. for about 50 miles up to the town of Northampton, where a canal branch ascends by 112 feet to the Grand Junction canal. The improved river navigation was opened to Northampton in 1761.

By means of Well Creek, the Nene communicates with the Ouse near Salton ford; and by 34 Geo. III. a still more direct navigation has been formed from Wisbeach to Lynn. This canal is about 6 miles in length, embanked through the fens. From the old sluice at Wisbeach to the Well Creek at Outwell, it has a flood lock at each extremity of 14 feet in width.

The Ouse navigation commences from the Sea in Lynn Deeps, below Lynn. Thence passing the town of Lynn, and by the Eau Brink, already described, to Salter's Load and Denver's sluice, it is thus far an open cut embanked tide river. Above Denver's sluice, the original Ouse proceeds still by an embanked and crooked channel through the fens to Ely and Hermitage sluice, near Erith. From this place the navigation continues by the natural bed of the river to Bedford, in all about 80 miles.

The branches of the Ouse are, the Lynn navigation, from that town, 15 miles, to Norford in Norfolk. About 17 miles above Lynn, at Salter's Lode, the Well Creek forms a communication with the Nene and Wisbeach canal, and hard by are the outlets of the Old and New Bedford rivers. Here also the Stoke river falls in, navigable for about 8½ miles eastward of Stokeferry, by an embanked channel through the fens.

Proceeding upwards, we find, at Rebeck, the Little Ouse or Brandon river, navigable for about 20 miles eastward to Thetford, the lower part of its course embanked through fens. Continuing up the Ouse, we have at Prickwillow, 5 miles below Ely, the Lark or Mildenhall river, which is navigable for 22 miles south-east to the town of Bury St. Edmunds. The Soham Lode is navigable for 4 miles to Soham. At Harrimere, above Ely, is the Cam or Grant river, navigable 14 miles to the city of Cambridge. There is also a branch of 3 miles to Reche, and another of 3½ miles to Burwell. This river is embanked in the lower part, and provided with sluices for making flashes of water, to enable loaded boats to pass the shallows. From Clayhithe sluice, 7 miles below Cambridge, the Cambridge and London canal was, in 1813, proposed to join the Lea navigation.

The boats in the Cam river are about 45 feet long, and from 8 to 10 feet wide, drawing 2 feet 8 inches, and carrying about 18 tons. They are furnished with decks, and raised in the fore part. As they have, below Denver, frequently to pass through rough water, they have a mast 36 feet high, and a square sail.

In Bedfordshire, the Ivel river proceeds from the Ouse at Temsford; and by 30 Geo. II. was made navigable to Biggleswade. It was generally proposed to extend the navigation 5 miles to Shefford. The locks are of a very rude description.

It is evident that the whole system of navigation in this fen district, is of that kind which we have called agricultural; that is, the import of coals, deals, and other commodities for the consumption of the country, in return for agricultural produce. Much of the corn, especially for malting, is taken to London from the heads of the navigation, as at Cambridge, &c. by land carriage; but the greater part is shipped from the ports on the Wash, as Lynn, and Boston.

Before leaving this district, we may notice a considerable natural navigation in the eastern part of the county of Norfolk. At Yarmouth is the mouth of the united rivers the Yare and the Waveney. The latter forms the boundary between the counties of Norfolk and Suffolk, and is navigable about 25 miles to the town of Bungay. The Yare is navigable 22 miles to the city of Norwich. It supplies that populous and manufacturing town, and serves for the export of agricultural produce from those extensive and well cultivated districts.

The Central District.

Having described the principal navigations, whether natural or artificial, connected with the coasts of South Britain, we now proceed to give an account of those important lines of canal navigations, which serve to connect the populous and industrious districts on the Mersey and Trent with the Severn and the Thames. The father of this great project was the Duke of Bridgewater; for, after the completion of his canal, there seemed no physical difficulties but which might be surmounted by skill and perseverance. It was, therefore, immediately proposed to connect the Mersey with the Trent, by proceeding from the Duke's canal, and penetrating through the ridge called Harecastle Hill, by means of a tunnel; and this project was named the Grand Trunk. This being approved of and begun, the scheme was soon greatly extended, by carrying a branch from the grand trunk at the town of Stafford to the river Severn at Stourport. Two years afterwards, in 1768, acts were obtained for extension to the towns of Birmingham and Coventry; and next year for a continuation of a long line by Banbury to the river Thames, at the city of Oxford.

The farther progress of canal navigation seemed to be checked, until some years after the conclusion of the American war, when the improvement of the coal and iron trades, and the general application of the lately improved steam-engine to machinery, (more especially in the latter manufactures,) gave new life to these undertakings. Numerous projects were brought forward, and of these, the Grand Junction, begun in 1793, completed the connection between the manufacturing districts in the interior and the metropolis, without the vexatious delays of the river Thames.

In describing the central district, we shall first consider the Grand Trunk, with its important branch the Staffordshire and Worcestershire canal; then abandoning the order of time, we shall proceed from the metropolis by the Grand Junction canal along what now forms the great line of traffic, and also consider the numerous canals on either side, as being collateral branches connected in business with it.

The Grand Trunk was so named, as passing through the central parts of the kingdom, and being the great link connecting the Mersey, Trent, and Severn rivers. From its commencement at the mouth of the river Derwent in Derbyshire, to the Derby canal at Swarkstone, is 6 miles, with a rise of 32 feet by 4 locks, for vessels of 14 feet beam; thence to Hornington wharf near Burton 10 miles, the rise being 16 feet by two locks for 7 feet beam. From this wharf to where the Coventry canal turns off at Fradley heath 12 miles, with a rise of 86 feet by 11 locks. From this point to where the Staffordshire and Worcestershire departs at Heywood, 13 miles, the rise is 32 feet by 4 locks; thence to Etruria, near Newcastle-under-Line, 17 miles, with a rise of 150 feet by 19 locks. From this place the summit level continues through Harecastle tunnel to near Talk, 6 miles. From the northern extremity of the summit level to the town of Middlewich, 11 miles, the fall is 326 feet by 35 locks. From this town the canal proceeds past Northwich, along the north bank of the river Weaver, and through three short tunnels to Preston Brook, in Cheshire, where it terminates in the Duke's canal. This last is a distance of 18 miles, all in one level. From the river Derwent at Wilden ferry, to near Burton, this canal admits boats of 14 feet beam; all the rest of this canal and its branches are for 7 feet beam only. The branches are, one from near Burton, of about a mile, to the river Trent. From Stoke, near Newcastle, there is a railway to Lanes End 3 miles. From Etruria there is a railway to Hornby Green and Burslem potteries. From Longport to Dolehall there is a canal branch, and thence a railway to Burslem potteries. Adjacent to Etruria, the branch named the Caldon canal proceeds, by a circuitous course, near Stanley Moss and Froghall to Utoxeter, in all a distance of 28 miles. From this summit, near Etruria, this Caldon branch or canal proceeds 5¾ miles to the eastward of Norton Green, on the road to Leek: in this last distance there is a rise of 75 feet by 7 locks. From this point to Stanley Moss, one mile, is the summit level; thence to Froghall is 9¾ miles, with a fall of 61 feet by 9 locks. From this place to Utoxeter is 11½ miles. With this long branch is connected one from Stanley Moss, 3½ miles, to the town of Leek; a short cut from Skelton to Cobridge, and a railway from Froghall, 3¼ miles, which ascends to the Caldon Low limeworks.

On the main line there are five tunnels, viz. one 130 yards at Armitage; one 2888 yards upon the summit through Harecastle Hill; one on the north bank of the river weaver 570 yards; Suttersford tunnel 350 yards; Preston Hill tunnel 1241 yards; Harecastle tunnel is only 9 feet wide, and 12 feet high; all the others are 13 feet wide, and 17 feet high. In Rudyard Vale, above Leek, there is a reservoir of 160 acres, with a head 30 feet high; near the summit there are four other small reservoirs, in all about 60 acres. The canal was begun in 1766, and the main line opened in 1777.

Besides the raw materials and manufactured goods connected with the numerous potteries, and the supplies of merchandise, the thorough trade of this canal is so extensive and various that it cannot be specified. The acts are 6, 10, 15, 16, 23, 25, 37, 42 Geo. III. The engineers employed were, James Brindley, John Smeaton, Hugh Henshall, and John Rennie.

From Stoke a branch proceeds, in a very circuitous manner, past the town of Newcastle, and thence to the Apdale and Partridge collieries: the whole is only about 8 miles in length. It consists of three separate properties under separate acts. Beginning at Stoke, the first three miles reaching the town is named the Newcastle-under-Line canal. Its act is 35 Geo. III. Next is the Newcastle-under-Line junction, which comprehends a short piece at either end of the remainder, by act 38 Geo. III. Lastly, Sir Nigel Gresley's canal, which occupies the middle space between the two last mentioned portions, under act 15 Geo. III. The purposes of these united canals are, to convey the Updale and Partridge coals from the westward, and the Caldon lime from the eastward.

The line of navigable communication between the metropolis and the central parts of the kingdom, was formerly accomplished by the river Thames to Oxford, and of late years extended by means of the Oxford canal to Coventry. But the city of Oxford lies considerably to the westward of a straight line from London, and the crooked course of the Thames, together with its very imperfect navigation, suggested the idea of an artificial canal from the vicinity of Daventry; but having to cross the intervening ridges and vallies, obstacles of no common magnitude embarrassed the project. Yet these have been all surmounted, and the extensive intercourse now carried on fully justifies the scheme, which obtained the appropriate name of the Grand Junction Canal.

The earliest promoter of this canal, we have been informed, was William Praed, Esq. who having prevailed on the Marquis of Buckingham to patronize the project, an act of Parliament was obtained early in 1793. The general direction of the canal is north-west, through the counties of Middlesex, Hertford, Buckingham, Bedford, and Northampton; and the main line is 95 miles in length. It commences in the Thames at Brentford, from which it proceeds to the valley of the Colne, near

Cowley, and continues to follow it past Uxbridge, Rickmansworth, Walford, King's Langley, Two Waters, Berkhampstead, to Cow Roast, being 35 miles 2 furl. 8 ch. with a rise of 395 feet, and through an almost continued succession of mill pools. The summit level is only 3¾ miles in length, and mostly in deep cutting.

From the northern extremity of the summit the canal passes by Marswath, near to Leighton Buzzard and Fenny Stratford to the Ouse at Wolverston, near Stoney Stratford, a distance of 25 miles 1 furl. 6 ch. with a fall of 192 feet. It here crosses the Ouse and valley by an embankment about half a mile in length, and 30 feet high, with a small iron aqueduct. From thence the canal passes along the western side of the Five Rivers, and having crossed it, arrives at Stoke Bruern, being a distance of six miles 4 furl. 4 ch. with a rise of 112 feet. It here passes through Blisworth tunnel, which is 3080 yards in length, 18 feet high, and 16 feet 6 inches wide, and proceeds by Western Beck to the south end of Whitton Parish, in all 13 miles 3 furl. 6 chains, on one level. It then passes to Whitton Mill, a distance of 5 furl. 5 ch. with a rise of 60 feet; from that place is a level of 4 miles 2 furlongs to the farther end of Braunston tunnel, which is 2045 yards in length, and of the same height and width as that at Blisworth. From the western end of the tunnel to the junction with the Oxford canal is 7 furl. 3 ch. with a fall of 37 feet.

Half way between Brentford and Uxbridge, at about 84 feet above the level of the Thames, a branch proceeds upon one level 13½ miles to Paddington, where it terminates in an extensive basin, where numerous warehouses have been erected, to accommodate a great portion of the trade between London and the interior of the country.

From the northern extremity of the Tring summit, a branch passes off, and proceeds upon one level, 6¾ miles, to near the town of Wendover. It is chiefly for supplying water.

A little way north of the Tring summit, and 45 feet below it, a branch passes 6 miles to the town of Aylesbury, having a fall of 95 feet by 14 locks. This branch is partly for the supply of that town and neighbourhood, and chiefly as a step towards forming a junction with the Wilts and Berks canal at the town of Abingdon, to which there is a fall from Aylesbury of 96 feet.

The next branch proceeds from the west end of Wolverton embankment, and passes up the north bank of the river Ouse 9½ miles, with a rise of 13 feet, to the town of Buckingham, chiefly for supplying that town and neighbourhood with coals and other articles.

A little west of Blisworth tunnel at Gayton, a branch of 5 miles passes to the river Nene, at Northampton, with a fall of 112 feet, to supply that place and neighbourhood, and open a direct communication from it with London.

The last operations upon the main line of canal, were the embankment at Wolverton, and the tunnel at Blisworth. These were completed, and the whole navigation from London to the Oxford canal at Braunston opened in 1805. The trade is various and great, and the revenue in 1813 was 168,390*l.* notwithstanding the following low rates of tonnage, viz. lime and limestone a farthing per ton per mile; all other stone, brick, slate, pig-iron, lead, and all sorts of manure, one halfpenny; coal, coke, three farthings; other goods, merchandise, one penny per ton per mile.

The execution of a line of canal through so great an extent of country presented a variety of new views and interests, and of course required a number of separate acts, viz. 33, 34, 35, 36, 38, 41, 43, and 45 Geo. III. William Jessop was employed as engineer in planning the works, and while they were executing; and Thomas Telford was employed to examine and report their state previous to opening the Blisworth tunnel, and the whole navigation, and continues to be the chief engineer for that great company.

The width of the main line is 36 feet at top water, and 24 feet at bottom, with 4½ feet depth of water. The locks are 85 feet long, and 14 feet 6 inches wide. Some of the branches are for 7 feet boats.

The Grand Junction Canal having opened a communication between the great manufacturing districts in the interior of the kingdom and the metropolis, created a great depot at the western suburb at Paddington; but the city of London and all its eastern extremities were still very distant, and difficult of access; and these circumstances gave rise to the project named the Regent's canal.

It departs from the Grand Junction canal at Paddington, and passes for a little way in open cuttings. It then crosses the Edgeware road, and some high ground in a tunnel about a quarter of a mile in length. It afterwards proceeds chiefly in deep cutting, along the northern side of the Regent's Park to the Hampstead road, near to which a branch, three-fourths of a mile in length, passes along the eastern side of the park to an extensive basin, all hitherto on the same level as the Grand Junction Paddington arm. After crossing the Hampstead and Highgate roads, the line crosses the fields to Islington, having descended by four locks. It next passes under Islington by a tunnel 900 yards in length.

From the eastern extremity of the tunnel, the line passes through rich pasturage fields to the inn called the Rosemary Branch, having descended by two more locks, and had a short branch taken off, in order to approach the central parts of the city of London. From the Rosemary Branch the canal passes the Kingsland and Haggerstone roads to the Hackney road on Cambridge heath, in which distance there is one lock. It afterwards passes by Bonner's Hall to Mile End road. This distance has two locks. It then crosses the commercial road immediately on the eastern side of Messrs. Brunton's patent cable chain manufactory, and after crossing a field and Queen-street, terminates on the north bank of the river Thames at Limehouse. In this last division there are two locks, which, with the tide lock, makes in all 13. The whole length of the canal being 8¾ miles, and the fall from Paddington level to the high water of the Thames at Limehouse 84 feet. The tide lock and basin will receive coasting vessels, and the rest of the canal river barges. It is thirty feet wide at the bottom, and 45 feet at top water, which is to be 5 feet deep.

By the original act this canal was to have had all its water pumped up from the river Thames; but an arrangement has been lately made for the Regent's Canal Company to supply the Grand Junction water works with water from the Thames, and, in lieu of this, to derive a supply for their canal from the Paddington level of the Grand Junction canal, which formerly went to the said water works.

It is expected that a great proportion of the trade, which now passes by Brentford, or is transacted at Paddington, will be transferred to the before mentioned basin, adjacent to the central parts of the city of London; and that all the northern side of that city and Westminster, as well as the adjacent extensive suburbs, which are at present supplied from the river Thames by an extensive cartage across the city, will in future be supplied by the Regent's canal. If these expectations are verified, the proprietors will be amply remunerated, although they have unavoidably had to contend with many obstacles, and incur much expense. Mr. Morgan is the engineer employed by the Regent's Canal Company, and Thomas Telford by the Grand Junction Canal Company, and the commissioners for Exchequer Bills, which have been lent to complete the work.

At the north-west extremity of the Grand Junction, the Oxford canal not only extends the connection of the former with the interior, but opens an important communication between this great summit of the country (in a south-west direction) with the river Isis at Oxford, and also the extensive track through which it passes. This canal leaves the Coventry canal at Longford, about 4 miles north of the town of Coventry, and proceeds upon one level across the upper part of the valley of the Warwick Avon to near Hill Morton, a distance of 26 miles 4 furlongs 3 chains. Near to Hill Morton, in the distance of 3 furlongs 7 chains, there is a rise of 18 feet 10 inches by three locks. From this place to Napton, 16 miles 6 furl. the line is level. About the middle of this distance the Grand Junction passes off; and near Napton on the Hill the Warwick and Napton canal. From the last mentioned point the canal proceeds by Doles wharf, a distance of 1 mile 7 furl. 3 ch. with a rise of 55 feet 3 inches, by 9 locks. It has here reached its summit level, which continues 10 miles 6 furl. 7 ch. to Claydon, having, by means of a tunnel 1188 yards in length near Teney Compton, passed a ridge, from which the water on one side flows to the Severn, and on the other to the Thames. From Claydon the canal falls into the valley of the Charwell, and proceeds to the town of Banbury 7 miles 2 furl. with a fall of 77 feet 4 inches by 12 locks. From Banbury the canal follows the Charwell, crossing it near Hampton Gay, and passes to the river Isis at Badcock's garden, on the east side of Oxford. The distance from Banbury is 27 miles 2 furl. with a fall of 114 feet 5 inches by 17 locks. At Oxford there is a lock with a fall of 3 feet 6 inches into the Isis. Its total length is 91 miles.

The canal is 28 feet wide at the surface of the water, 16 feet at bottom, and generally 4½ feet deep; the summit is 6 feet deep. The locks are 75 feet long, and 7 feet wide at bottom. There are nearly three bridges in a mile on an average. In 1769 Mr. Brindley's plan was approved of, and the work begun. In 1775 the canal had reached Napton, and Banbury in 1778. In 1786 the work was resumed, and in 1790 it was completed to Oxford.

At Hill Morton there is a branch half a mile in length, and another of the same length at Napton. These two are on the same level as the canal to the steam-engine for pumping up water to supply the canal. There is a third branch of a quarter of a mile, which connects with the Isis navigation at Godstow. This last branch belongs to the Duke of Marlborough. The steam-engine at Hill Morton pumps water from the lowest or long level into the Napton level, and that at Napton from this last mentioned level up to the summit. There are also reservoirs to supply the summit.

This canal was formed chiefly to convey coal from the counties of Warwick and Stafford to Oxfordshire, and the city of Oxford, for the exportation of agricultural produce, and by means of the river Isis and Thames to form an intercourse with London. The acts are 9, 15, 26, 34, 39 Geo. III.

At the north-west extremity of the last canal the Coventry canal commences, and passes by that populous town, also Longford and Nimeaton to Atherstone, 16 miles 6 furls. upon one level. From Atherstone to Fazely near Tamwath 10 miles, there is a fall of 96 feet by 13 locks. From Fazely to the Grand Trunk, or Trent and Mersey canal at Fradley heath, near Litchfield, is 11 miles, and level; but the first 5 miles of this last portion belongs to the Birmingham canal, and the part next the Grand Trunk to the Coventry canal; so that this navigation altogether on the main line, from the town of coventry, is 32 miles 2 furlongs. The canal and locks are for narrow boats. The purposes of the canal are for the conveyance of coals, and all sorts of goods between the Trent and Mersey canal, and the Oxford and Grand Junction canals. It was made from Coventry to Atherstone in 1786, and the whole communication opened in 1790. James Brindley was engineer. The acts are 8, 25, 26 Geo. III.

At Marston Bridge, the Ashby de la Zouch canal passes off. At the same place, at the opposite or western side of the canal, there is a branch which is separated into five cuts to accommodate several collieries. A little farther, another branch of about a mile passes to the Griff collieries, which belongs to Sir Roger Newdigate. At Fazely is the junction with the Birmingham and Fazely canal; and near Litchfield the Wierley and Essington falls in, and the united canals join the Grand Trunk. This canal completes the communication between London and the Trent and Mersey navigation, nearly in the centre of England; and, having thus completed the main line, we shall return to the central summit, and proceed to describe the congeries of canals roud Birmingham, and between this main trunk and the river Severn.

From the Oxford canal, near Napton on the Hill, the Warwick and Napton canal departs, and takes a pretty direct course towards the town of Warwick, near which it crosses the river Avon by an aqueduct, and terminates in the Warwick and Birmingham canal, after a course of about 15 miles, on the same level as the last-mentioned canal. It was completed in 1799. The acts are 34th and 36th Geo. III.

From the Warwick and Napton, near the town of Warwick, proceeds the Warwick and Birmingham canal to the town of Birmingham, a distance of about 25 miles, and joins the branch from the Fazely canal. From its commencement the first half mile is level; thence to Hatton, 2½ miles, by 20 locks; from Hatton to the Statford junction branch, five miles are level; and this continues to Knoule common, where, in one mile, there is a fall by seven locks; from this point to Directend, near Birmingham, 10 miles are level; thence to the junction with the Fazely branch, 1½ miles, there is a rise by five locks. This canal was finished in 1799. The acts are, 33d and 36th Geo. III.

By this, and the Napton and Grand junction canals, Birmingham has a very direct communication with London.

We have now reached Birmingham, as much distinguished for the singularity of its inland navigation, as for the variety, ingenuity, and excellence of its manufactures; for, notwithstanding its situation in a high summit, almost destitute of water, navigable canals diverge from it, by means of lockage, in all directions. What nature seems to have denied, human ingenuity and skill have accomplished. The mines which supply the materials for manufactures, are made to afford the means of carrying the produce of the manufactures to market; for the water, which was not to be had on the surface, has, by the aid of powerful engines, been drawn from the bowels of the earth. We must, therefore, from this centrical situation, take a hasty survey of its numerous canals; and shall begin with that which proceeds from the termination of the line which we last described.

The Birmingham and Fazely canal commences at the termination of the Birmingham and Warwick canal, in that part of the town of Birmingham called Digbeth, and skirts its base to Farmer's Bridge, and thence along the valley of the Tame, past Cadwath and Fazely, and terminates in the before-mentioned detached part of the Coventry canal, in all a distance of 20½ miles; for the first 1¼ miles from Digbeth, is a rise of 40 feet by six locks; from thence to the Old Birmingham canal at Farmer's Bridge, 1½ mile, there is a rise of 85 feet by 13 locks; from the junction of the Digbeth branch, to the aqueduct over the Tame at Salford, is 1½ mile, with a fall of 71 feet by 11 locks; thence to Middleton Hall is 9¾ miles, with a fall of 90 feet, by 14 locks; and from the latter place to the termination in the Coventry canal, 5½ miles north of Fazely, is 8¼ miles level. A part of the Digbeth branch is tunnelled under the town. This canal, opened in 1790, forms a direct line from Birmingham to the Grand Trunk canal, and, of course, to Liverpool and Hull. The acts are, 23d, 24th, 25th, 34th, Geo. III. It is now the property of the Old Birmingham company. It is made for boats of 70 feet in length, and 7 feet wide.

The Old Birmingham canal departs from Farmer's Bridge, and proceeds by a very crooked course past Smithwick and Oldbury, near to Dudley. It then passes to the east of Tipton, the west of Bilstone, and the east of Wolverhampton, to the Staffordshire and Worcestershire canal at Autherly, a distance of 22½ miles. For 4½ miles from Smithwick, it continues level, but there it descends 18 feet by three locks. From this place, to within two miles of its junction with the Staffordshire and Worcester canal, it is level; but in the last space falls 113 feet by 17 locks. At two places the canal is doubled: first, near Smithwick, where, on account of the great press of business, a new cut has been made, with three locks, parallel to those originally constructed; secondly, at Tipton, where a passage of 1½ mile has been made through the hill, in order to avoid a crooked course of four miles. Upon this new line there is a tunnel of 1000 yards in length.

The branches from this canal are very numerous at Birmingham. One passes to Newhall Ring Basin, another to Soho Foundery; and, at Bromwich, that to Wednesbury and Walsal goes off, and is 8¼ miles in length. At the point of separation it falls 18 feet, by three locks; at Ryder's Green it falls 48 feet by six locks; the remainder is level. Nine branches go from this to distinct works; that to Toll End rises 15 feet by three locks; that to Bradley rises 20 feet by four locks. All the others are level. From the main line, east of Tipton, there is a branch of one mile, to Oker hill.

This canal is for 70 feet boats, of seven feet beam. Some water is supplied on the summit from one reservoir at Oldbury, and another at Smithwick; but its chief dependance is upon steam engines from the water of old works, and returning the water from the lower to the higher levels. The trade of this canal, which is very great, consists of the raw materials and manufactured goods of Birmingham, and the supply of that populous and industrious place. The acts are, 8th, 9th, 11th, 23d, 24th, and 34th of Geo. III. James Brindley was the engineer.

From the Birmingham canal, at Wolverhampton, passes off the Wyerley and Essington canal. It proceeds past Polsal, the south-east corner of Connock Heath, and Litchfield, to the Coventry canal, about five miles from the Grand Trunk on Fradley Heath. The length of the main line is 24 miles. The first 16½ are level. On the remainder there is a fall of 264 feet by 30 locks.

This canal has various extensive branches. A little to the east of New Invention, is a branch to Wyerley bank collieries; it is four miles long, and ascends 36 feet by 6 locks. From it passes off a branch, a mile in length, to Essington collieries; which ascends 24 feet by four locks. Near to the town of Walsal, is a branch for half a mile on a level. Near Palsal is a level branch, 2½ miles, to lord Hay's collieries. From Cannock Heath is a branch to Hay Head lime works. It is six miles, and level. The canal is 28 feet wide at top water, 16 at bottom, and 4½ deep. The locks are for 70 feet boats, of 7 feet beam. It is chiefly for coal and lime. The acts are, 32d, 34th Geo. III. The engineer was William Pitt.

Not satisfied with the communication with the Severn, by Wolverhampton and Stourport, a more direct line has been found from Birmingham immediately to the city of Worcester. A canal passes off from Newhall Ring basin, and proceeds by Edgebarton and King's Norton, to Tardebig, 14 miles upon the summit level. In this distance there is a tunnel of 110 yards at Edgebarton, a second of 2700 yards at West Hill; a third of 400 yards at Short Wood, and a fourth of 500 yards at Tardebig. In 1798, the navigation was opened to Tardebig. This part of the canal is 42 feet wide at top water, which is six feet deep. The tunnels are 18 feet 6 inches wide, and 18 high, with seven feet two inches water. From Tardebig to the Severn, at the city of Worcester, a distance of 15 miles, there is a fall of 428 feet. For this portion many projects have been proposed, and some attempted, such as caissons and inclined planes; but, after an interruption of several years, it has at last been completed by narrow locks.

From the last mentioned canal at King's Norton, about six miles from Birmingham, that of Stratford-upon-Avon proceeds in a nearly southern direction, by Lapworth and Preston Mill, to Stratford, a distance of 23½ miles. From King's Norton to Hockley Heath, 10 miles are level; from that to Lapworth, 2¼ miles, there is a fall of 147 feet; thence to Preston Green one mile is level; to Preston Mill, 1¾ miles, is a fall 76 feet; from thence to Wilmcote 6 miles are level; afterwards, in one mile, there is a fall of 86 feet; then to Stratford 1½ mile is level.

From Hockley Heath, a branch 2½ miles passes to Tanworth quarries, upon the summit level; from near Lapworth, a branch proceeds 1¾ miles to the Warwick and Birmingham canal. Near Aston Cantelaw, is a branch four miles to the Temple Grafton lime works, with a rise of 20 feet. In May 1796, the canal was opened from the Worcester and Birmingham to Hockley Heath. The trade is chiefly in coal, lime, and paving-stones. The acts are, 33d, 35th, 39th, Geo. III.

From the Worcester and Birmingham, about three miles from the town, at Selby Oak, the Dudley canal goes off, and passes a little east of Hales Owen, and north of Dudley town, to the old Birmingham canal, near Tipton. From near Dudley, the canal proceeds to the Black Delph and Stourbridge canals. From its commencement to the Black Delph, 10½ miles is level; thence to Stourbridge it falls 85 feet by nine locks. From the main line to the entrance of Dudley tunnel, ¾ of a mile, it rises 31 feet by five locks. Through the tunnel, 2926 yards is level; thence to the old Birmingham, one furlong, it falls 13 feet by two locks. There is a branch to Dudley town 1¼ mile, with a rise of 64 feet, from which there is a level branch ¾ of a mile, to Dudley coal works. On the canal there are three tunnels, one at Capal, 3776 yards in length, another at Gortsy hill, 623 yards, and the one before-mentioned at Dudley, 2926 yards. At Bradley there is a reservoir, which supplies water for lockage to the Stourbridge canal at Black Delph. The trade is in coals, lime, and iron. The acts are, 16th, 25th, 30th, 33d, and 36th Geo. III.

Next, in a westerly direction, is the Stourbridge canal. From the termination of the Dudley canal, one branch, on the summit level, passes eastward two miles to Pensant Chase, and a small branch, ¼ of a mile adjacent thereto, is a reservoir of 12 acres, which supplies the summit. From the junction eastward to the Lays, 1½ mile is level; thence to the Stourbridge branch, 1⅛ mile, there is a fall of 148 feet by 16 locks. The Stourbridge branch, of one mile, is level; and from it to Stewponey the line is also level. In the last three furlongs, there is a fall of 43½ feet, into the Staffordshire and Worcestershire canal. The canal is 28 feet wide at top water, and 5 feet deep. The acts are, 16th and 22d Geo. III. Articles of trade, coal, iron, glass, Stourbridge fine clay, &c.

The Staffordshire and Worcestershire canal commences in the Grand Trunk at Heywood, crosses the river Trent, and passes a little south of the town of Stafford and Penkridge, in the north of Wolverhampton, south of Autherley and Tettenhall, north of Stewponey, and through Kidderminster to the river Severn at Stourport; in all a distance of 46½ miles.

From Heywood to the north end of the summit, on the old Roman Watling-street road at Streetway, the distance is 13¼ miles, with a rise of 100½ feet by 13 locks. From Streetway to Tottenhall the summit level is 10 miles. At Autherton, the old Birmingham canal falls in. From Tottenhall to Stewponey, where the Stourbridge canal falls in, is 11 miles, with a fall of 165½ feet by 18 locks. From this place to Stourport, 12 miles, there is a fall of 127½ feet by 13 locks. At Stourport there are two basins, with extensive wharves and warehouses, and two sets of locks into the Severn, one for river vessels, and the other for small canal boats. In the course of this canal there are three short tunnels, and three small aqueducts. The canal was begun in 1766, and completed in 1772. There is one reservoir at Chittington, and one at Mosely, from which the summit level is supplied. The trade is very great, and consists of coal, iron, hardwares, earthenwares, glass, general merchandise, and fruit from the counties of Worcester and Hereford. The acts are, 6, 10, 30 Geo. III. The engineer was James Brindley.

Having described the navigations on the western side of the Grand Junction line, we must return to our general summit at Daventry, adjacent to which, from the Grand Junction canal, near the eastern extremity of the Braunston tunnel, proceeds the Grand Union canal. It has a double lockage and two tunnels, and passes at no great distance from the Oxford canal. It unites the Leicestershire and Northamptonshire canals with the Grand Junction canal. From the Grand Junction, near lock Buckley wharf, it passes about 5 miles upon a level; it then ascends 54 feet by 7 locks; it then proceeds 18 miles upon the summit level, and afterwards descends 76 feet by 10 locks, and unites with Leicester Union canal, near Foxton. The summit level passes two tunnels of considerable length; that is to say, one at Bosworth, 1166 yards in length, and another at Crick, 1524 yards. These are sufficiently wide to admit barges of 14 feet beam. The locks are only for boats of 7 feet beam. The act was obtained in 1810. The works were completed, and the canal opened in 1814. The engineer was Benjamin Bevan.

The Union or Market Harborough canal was, according to the original design, to have proceeded from the river Soar at Leicester, by Market Harborough, and across the valley of the Welland, to Oxenden, and then to have fallen down 197 feet to the Nene at Northampton, which would have been in all a distance of 43¾ miles. From the Nene a line was to ascend by the Grand Junction branch, 112 feet to that canal, a little north of the Bilsworth tunnel.

The portion of this canal now executed, commences in the river Soar, near Leicester, at a place called West Bridge. It proceeds about 3 miles parallel with that stream, and thence to Saddington, a distance from Leicester of 12¾ miles, with a rise of 160 feet. At Saddington is a tunnel 880 yards in length, through which the canal proceeds on a level 2¼ miles to Gumley wharf, where, to avoid the Foxton tunnel, upon the parliamentary line, there is a direction surveyed by Thomas Telford, by which the canal is carried on a level for six miles to the town of Market Harborough; and here the canal terminates.

But Mr. Telford's survey was continued across the Welland Valley, and thence to Oxenden, where it ascended 23 feet by three locks; and thence proceeded, on the same level, to the Grand Junction at Buckley Wharf. From Arthington a level branch proceeded six miles to the limestone quarries at Rushton, making in all a summit level of about 30 miles, and that corresponding with the Grand Junction summit at Braunston, would have added 4 miles more, say 34 miles of summit. The objects here were chiefly agricultural, viz. the coals from Derbyshire, in one direction, and by the Oxford and Grand Junction Canals in the other; but both led to the limestone quarries in Northamptonshire, and thence exported lime in all directions. General merchandise, for the consumption of the populous country, would also have been considerable; but the views of the Grand Junction proprietors being chiefly commercial, the most direct line between Buckley and Gumley Wharfs was preferred, although passing near to the Oxford Canal, and encumbered with a double lockage and two tunnels.

The only other important branch, to the eastward, is the Ashby de la Zouch Canal, which passes northward to the town of that name, by a very circuitous course, south of Hinckley, from the Oxford Canal at Marston Bridge, near Nuneaton, in all a distance of 40 miles.

From the Oxford Canal past Hinckley, to Oakthorpe engine, upon the Ashby Wolds, a distance of 30½ miles, the canal is upon one level; from this place to Boothorpe feeder, 1¾ mile, there is a rise of 140 feet. The summit level then continues 4¼ miles to the north end of the great tunnel, and thence, to the Cloudshill branch, a quarter of a mile, the fall is 84 feet. A water branch goes 2⅛ miles level to Swadlingcote coalworks; another of seven furlongs, with a fall of 28 feet, to Stainton limeworks; a third of 200 yards level, to Hinckley Wharf. There is also a railway 5¼ miles to Ticknall lime works, and another, 5 miles, to Mr. Wilkes's Measham collieries. There is one tunnel [illegible] yards in length, at Ashby de la Zouch, and another 200 at Snareston. At Boothorpe is a large reservoir, from which water is raised by a steam engine into a feeder, which conducts it to the summit level. This navigation was completed in 1805. Act 34 Geo. III.

Scotland.

The northern division of Great Britain, called Scotland, being chiefly mountainous, its general appropriation will probably always be pasturage. Although, in some parts of the country, agriculture has of late years made rapid and successful progress, yet the districts proper for it are of small extent, the valleys narrow, and the hills approaching near to the sea-shore. It is fortunate that the central parts abound in coal, lime, iron, and lead. The mountains, though numerous and lofty, are generally disposed in ridges and detached groups, separated by valleys whose elevations are small. Between the rivers Forth and Clyde, the highest part of the valley is only 156 feet above the tideway. The valley of Glenmore, or the Great Glen of Scotland, which passes from the Moray Firth, in the east, to the Linnhe Loch, on the west side of the island, is not 100 feet high. Many others, although not so correctly ascertained, appear to be equally low. The extremities of these valleys are generally filled with arms of the sea, while fresh water lakes not unfrequently occupy a considerable portion of their middle space. These valleys, being also generally exposed to temperate winds from the Western Ocean, are seldom much incommoded by frost and snow. These circumstances render them peculiarly suitable for lines of communication between different parts of the country, and accordingly several of them have from time immemorial been thus employed. In the reign of the Roman Emperor Antoninus Pius, a fortified wall and military road were constructed between the rivers Forth and Clyde, as a barrier against such of the natives as remained unsubdued. After that badge of foreign interference had been destroyed, the same pass received a principal road for the intercourse between the populous districts on the eastern and western side of the island.

In process of time, when inland navigation had made considerable progress on the Continent of Europe, the propriety of having one along this land-pass between the rivers Forth and Clyde became so evident, that in the reign of Charles II. there was a proposal for constructing a canal capable of receiving transports and small ships of war, the expense of which was estimated at 500,000*l.* The project was probably suggested by the then Duke of York, an experienced naval officer, and no doubt well acquainted with the inland navigation of France and Holland. That no practical measures were adopted, may be attributed to the turbulence of the times, or it may have been discovered, that although there was a sufficient depth of water in the river Forth, yet that the Firth of Clyde, above Port Glasgow, was unfit for vessels of the above-mentioned description. The subject was not resumed until the year 1722, and then only carried the length of a survey. In 1761 Lord Napier had a survey and plan made at his own expense. The subject having been thus fairly agitated, it was in 1763 taken up by the Trustees for Fisheries, and again in 1766, at the expense of a subscription in Glasgow; but these latter projects being only for a depth of from 4 to 5 feet water, were superseded by one to admit small coasting vessels, and Mr. Smeaton, one of the most eminent engineers of that day, was employed to survey the country, and prepare plans. Upon these an act of parliament was obtained early in 1768. Practical operations were commenced on the 10th of June, and in November 1777, the navigation was completed to Hamilton Hill, near Glasgow. In 1786, the extension from Kelvin to the Clyde was commenced, and completed to the tideway at Bowling Bay in July 1790. In November following it was carried to Port Dundas, and from thence to the Monkland Canal Basin.

The eastern extremity of this canal is in the small river Carren, near its junction with the Forth, where spring tides rise about 18 feet. At this place, called Grangemouth, there is a tide lock and basin. The latter is inconveniently small, and the entrance altogether imperfect. From Grangemouth the canal passes on the western side of the town of Falkirk, and from thence to the summit of the before mentioned low pass, a distance of about 10¼ miles, having ascended 156 feet by 20 locks. From this point the canal proceeds, on the summit level, for 18 miles, to the city of Glasgow, at Port Dundas. It also continues one mile beyond this place, to the Monkland Canal Basin, but in this last distance there is one regulating lock. About 2¾ miles north of Port Dundas, the branch to the Clyde goes off. It passes the Kelvin by a magnificent stone aqueduct, (see Plate CCCCXIV. Fig. 3 and 4,) and proceeds to the tideway at Bowling Bay, having descended by 19 locks. The length of this branch is 8¾ miles. The distance between Grangemouth on the Forth, and Bowling Bay on the Clyde, is 35 miles. The locks are 74 feet in length, and 20 in breadth, and when the canal is quite full, has 8 feet water on the sills.

This canal has proved a useful acquisition to the country, and of late years profitable to the proprietors. It is an instance of the efficacy of public aid. A loan of 50,000*l.* enabled it to be completed and brought into use. That sum has long since been repaid with interest, and there is now an annual revenue, varying between 40,000*l.* and 50,000*l.* The principal articles are corn, timber, sugar, herrings, and passage-boats.

It has already been observed that the eastern termination of this canal is imperfect. Instead of ending in the narrow and muddy channel of the Carron, at some distance from the Forth, the shore of which, at that place, is itself unfavourable, the canal should be continued to Borrowstounness, situated upon the main estuary, where the depth of water is greater at low water, and other circumstances more favourable; and as an act has been obtained for this extension, its evident advantages will, no doubt, in time, ensure its execution.

Although the canal now described opens a very valuable communication between the estuaries of the Forth and Clyde, and also with the city of Glasgow, yet having its eastern termination at Grangemouth, the immediate intercourse between the great cities of Edinburgh and Glasgow, and also that of a great extent of the intervening rich and populous country, was left subject to land carriage. This evident imperfection long engaged the attention of the enlightened inhabitants of these two great cities, and many schemes were proposed to complete an inland navigation between them. Different views of this important subject produced various and prolonged discussions, and for several years kept various canal projects afloat. That which has been at last adopted, consists in proceeding from lock No. 16, or the fourth below the eastern termination of the Forth and Clyde Canal summit, and ascending 110 feet, by 11 locks, to a height which enables the line afterwards to be carried immediately south of the town of Falkirk and Linlithgow, to the lowest practicable summit of that part of the country, and afterwards through a beautiful and rich district to the western suburb of the city of Edinburgh—in all a distance of about 30 miles, upon the same level as that near Falkirk. This canal was planned by Mr. Hugh Baird, the resident engineer upon the Forth and Clyde Canal; and Mr. Telford, who was occasionally consulted, approved of it, and recommended the additional plan of continuing the line from Falkirk to the eastern extremity of the Forth and Clyde summit, and considering the connecting lock, No. 16, as for the Grangemouth trade only. By this mode, the whole distance between the cities of Edinburgh and Glasgow will be distributed into two long levels, one of 28 and the other of 26 miles, separated at Falkirk by six locks. This, if executed, will permit the intercourse between the two cities to be carried on without interrupting the thorough trade to Grangemouth, and instead of taking water from it, will give an increase to the summit level of the Forth and Clyde Canal. There are three large aqueducts and one short tunnel in this canal.

From the eastern termination at Edinburgh, it is proposed to complete a communication, either by a canal or railway, with the town of Leith; and extensions may also be made into East Lothian to the eastward, and into Stirlingshire to the westward.

On the northern side of the Clyde valley, and immediately east of Glasgow, the Monkland Canal affords a cheap communication between the city, and the collieries in the parishes of Old and New Monkland, distant about 12 miles. It was suggested to the magistrates in 1769: they employed the justly celebrated Mr. James Watt, then resident in Glasgow, to make the necessary surveys and plans; an act was obtained, the corporation took shares in a joint-stock company, and the canal was carried 10 miles. For two miles from the basin at Glasgow it is level. At Blackhill it ascended 96 feet by an inclined plane; and from the top of this hill the canal proceeds 8 miles upon a level. In 1770. Messrs. William Stirling and Sons, (having previously purchased the whole canal stock,) along with the proprietors of the Forth and Clyde. procured a second act, with powers to make a junction between the navigations, build locks at Blackhill, extend the Monkland Canal to the river Calder, and thereby rendering it an aqueduct for the Forth and Clyde. This canal is 24 feet wide at the bottom, 34 at the top, and has 4 feet 6 inches of water. At Blackhill there are 8 locks of 12 feet rise, and at Sheepford two more, of 11 feet 6 inches each. Coal is the chief article of carriage, and some iron; also manure from Glasgow. The annual revenue has increased gradually to about 12,000*l*.

Besides supplying the city of Glasgow with coals, and the adjacent country with manure,—from the canal being in the midst of abundance of coals, with convenient communication both with the East and West Seas, its banks are considered favourable for manufactures; and from the eastern termination at the Calder, extensions may be made to the whole of the upper parts of Lanarkshire, and even into the counties of Peebles, Selkirk, Roxburgh, and Berwick, as has been shown by the survey made by Mr. Telford for the Glasgow and Berwick railways.

The river Clyde, as has already been observed, becoming shallow a few miles above Greenock, it is only vessels about 9 feet water which can reach Glasgow ordinary spring tides. This shallowness arises from the deposition of sand and mud by a great river, where it meets the influence of the tides. The estuary being here very wide, it will be difficult, probably impracticable, to remedy this defect. These circumstances, and the great change of direction near Greenock, subjecting vessels to frequent detention, combined with the increasing importance of the mines and manufactures in and near Paisley and Johnstone, and in all the valley which connects the counties of Renfew and Ayr, have led to the construction of a canal through the before-mentioned valley to the harbour of Ardrossan, which is situated at the northern extremity of the Bay of Ayr, in the general run of the tides has a sufficient depth of water, and aided by the vicinity of the excellent roadstead at Lamlash.

The canal commences at Glasgow, on the southern bank of the river Clyde, from whence it proceeds upon one level through a part of the town of Paisley, and three miles farther to the village of Johnstone, in all a distance of about 10 miles. Thus far has been executed, and affords great facility of intercourse to this industrious district. At Johnstone the line is to ascend 64 feet, and afterwards proceed upon one level along the before mentioned valley, and past the towns of Lochwinnoch, Beith, Dalry, and Kilwinning, to near Saltcoats, where it descends 110 feet to the harbour of Ardrossan, in all a distance of 30 miles from Glasgow. The canal is for 70 feet boats of 7 feet beam.

The harbour of Ardrossan is on a scale to accommodate West Indiamen, and of course all vessels of smaller dimensions; and from it vessels may arrive and depart at all times, a circumstance of no small importance to commercial and manufacturing districts and connections. This canal and harbour have been planned and carried on under the direction of Thomas Telford.

Returning to the east coast, and from the Frith of Forth proceeding northwards, we find the estuary of the river Tay affording navigation to the industrious and populous town of Dundee, and also 20 miles farther to the wharfs at the town of Perth. Beyond the Tay the Grampian mountains extend their rugged skirts to the sea-shore, without leaving any considerable valley, until at Aberdeen the valleys of the rivers Dee and Don diverge westwards to a great distance. In the valley of the Don there is a considerable extent of arable land, and much population. The industrious town of Aberdeen is the port of this district, and from it a canal has been carried 18 miles up the valley of the Don to Inverary. The rise is 169 feet by 17 locks, 15 of which are adjacent to the city. These locks are each 57 feet long and 9 feet wide, having with full water about 4 feet. To complete the project, the canal should be extended about 12 miles upon a level. The chief trade is coal and lime, imported from Sunderland, which are carried far back into the country. The canal was opened in 1805. This canal was planned by Captain George Taylor.

At the north-eastern extremity of Aberdeenshire commences one of the most extraordinary valleys in this, or perhaps any other country; the eastern portion of it, for about 80 miles, from Kinnaird's Head to where it contracts, at Fort George, is denominated the Murray Firth, and for about 12 miles to Inverness is also tideway. From thence, across the island to Fort William on the shore of Loch Eil, (an arm of the Western Ocean,) a distance of 60 miles, the valley is formed by two parallel ranges of very high mountains, whose sides are steep, and these general ridges seldom intersected by collateral valleys; the bottom is occupied partly by rivers, but chiefly by lakes, in one direct line, from sea to sea. Again, entering the tideway at Fort-William, the valley is continued still in a direct line, with lofty mountains on each side, about 50 miles further, opposite to the eastern end of the sound of Mull; and by passing along the eastern side of the island of Jura, a distinct valley is continued between it and the main land of Cantyre, making another distance of 50 miles; the western extremity being only fairly opened to the ocean near the northern base of Ireland, a distance from Fraserburgh on the east of about 250 miles, or about one half only of the present track by the Orkneys and Cape Wrath.

This extraordinary pass has excited public attention ever since the time of the Romans. In the curious map by Richard of Cirencester, (composed in the fourteenth century, and founded chiefly on Ptolemy's Tables,) a continued canal is represented along the whole of the valley between the east and West Seas. Of this, perhaps the most ancient of existing maps, a correct copy is inserted in the able memoir which accompanies Mr. Arrowsmith's excellent map of Scotland.

The magnificent remains of Urquhart Castle on the east, and those of Inverlochy Castle on the west, with the chain of vitrified signal forts along the valleys, and likewise the three modern forts, are satisfactory evidence of its having constantly formed an important political feature in the country. After having long been subservient to the purposes of contention and warfare, it occurred to their last agents, that it was at least equally well adapted for commercial intercourse, and the object, supplying the wants of the garrison at Fort Augustus, contributed to an experiment of navigating the largest lake. The importance of a general intercourse became, at last, so manifest, that in 1773, the trustees for the forfeited estates employed Mr. James Watt, (the celebrated improver of the steam engine,) then resident at Glasgow, to make a survey, and report respecting the practicability of connecting the lakes and forming an inland navigation. This able and enlightened person, having made the necessary surveys with his usual accuracy, gave a description of the valley; and stated that the regularity of this extensive track, in such a rugged country, was truly astonishing, and that the whole, as well as the communications with the respective seas, were particularly favourable for an *Inland Navigation.*

The forfeited estates being restored to the respective families, the office of trustees was of course abolished, and any project which might have resulted from the above-mentioned survey was lost.

From this time the subject lay dormant until 1802, when, during the administration of Mr. Addington (now Lord Sidmouth) the state of warfare in the northern parts of Europe, the best mode of promoting the fisheries on the coasts of Scotland, and the local events of the northern portion of the kingdom, having become objects of serious consideration, the lords of the treasury employed Thomas Telford, civil engineer, to make surveys of the whole coasts of Scotland, and also the interior of the northern counties, to report their present state, and his opinion as to various modes of improvement. The results of his extensive surveys and reports went to the establishing naval stations, improving ports, superseding ferries, by opening the country by means of roads and bridges, and constructing an inland navigation across the great glen of Scotland, which he designated the CALEDONIAN CANAL.

These reports appeared so important to the treasury board, and more especially to Mr. Nicholas Vansittart, who was then Secretary, and since Chancellor of the Exchequer, that the whole was immediately referred to a special committee of the House of Commons, who, after investigating the several subjects and examining evidence upon all the material points, recommended, that the whole should be carried into effect; parliament also approved of the plan, and two Boards were established under two separate acts, viz. one for constructing and improving harbours, and making roads and bridges; and the other for constructing the CALEDONIAN CANAL. These Boards have ever since been assiduously employed upon the objects committed to their charge, and these objects have been nearly all successfully accomplished.

Considering the facilities afforded by the lakes, and that it was desirable to accommodate the trade between the western parts of England and Scotland, and all Ireland; the eastern coast of Britain, the Baltic, and East Country; and also between the east coast of Scotland and the West Indies, and likewise to pass small ships of war; Mr. Telford recommended, and the Board adopted, a canal upon a large scale, viz. 120 feet wide at the water surface, 50 feet at the bottom, and 20 feet depth of water: the locks of 170 and 180 feet of length, and 40 feet wide; these dimensions being sufficient, both in single and united locks, to admit of the largest vessels trading between Liverpool and the Baltic, the average of West Indiamen, and a 32 gun frigate when fully equipped. It likewise appeared, by the evidence of commercial and seafaring men, that if a navigation upon this scale was accomplished, the frequent and serious losses sustained in navigating by the Orkneys and Cape Wrath, during the autumn, winter, and spring months, would be avoided; that it would at all times be much more direct, and that it would be particularly useful in the time of war.

On the eastern coast, the seas brought in by the east and north-east winds, instead of discharging their violence into the bottom of the Murray Firth, are checked by the long projecting point of Tarbet Ness, and are also made to expand upon the flat sandy shores of the Dornoch Firth. From the other points they are land winds. If vessels should be prevented by strong westerly winds from reaching Fort George, the Bay of Cromarty affords an excellent navigable roadstead. Opposite its entrance the Firth is about 7 miles in breadth, with from 7 to 13 fathoms water at spring ebbs: from the same place to Fort George, about 7 miles, there is from 5 to 9 fathoms in the north channel, the two singular slips of land, viz. Channery on the north, and Ardrossan (occupied by Fort George) on the south side, being each about a mile in length, and their points crossing each other, confine the channel to about one mile in breadth, and completely land-lock all the upper part of the Firth. The tides pass this narrow channel with a great velocity, and create a depth of from 19 to 21 fathoms. From Fort George, towards Culloden, is one of the best roadsteads in Britain, about 4 miles in length, and from 3 to 10 fathoms water. From Channery point to the mouth of the river Ness, a distance of about 10 miles, the whole is completely land-locked; here the Firth is narrowed to about half a mile in breadth at Kessock Ferry; above this Ferry the Firth widens very considerably, and is continued about seven miles to the village of Beauly.

Immediately to the west of Kessock Ferry, there is a roadstead in from 4½ to 7 fathoms water; and it is in this sheltered bay, in Loch Beauly, that the eastern extremity of the Caledonian Canal is connected with the tideway. To have 20 feet of water on the lower sill at high water in ordinary neaps (which rise there about 8 feet, and ordinary springs about 14 feet) it was necessary, from the flatness of the shore, to place the tide-lock about 400 yards from high water mark. In constructing this lock, very considerable difficulties were to be surmounted, from the softness of the ground; but, as the process will be described in another part of this article, we shall here only observe that the lock is 170 feet long in the chamber, 40 feet wide, and has a rise of 8 feet. From this lock the canal is formed by artificial banks, until it reaches high-water mark at Clachnacarry, where another lock of similar dimensions is placed upon hard ground. Immediately to the south of this there is a basin or floating dock, of 967 yards of length, and 162 breadth, with a wharf at the upper end, for the trade of Inverness and the adjacent country. At the southern extremity of the basin is a public road bridge, and adjacent to it four united locks, each 180 feet long and 40 feet wide, which together raise the canal 32 feet, being the height of the surface of Loch Ness in its usual summer state. From the top of these locks, the canal, 50 feet wide in the bottom, 120 at the water surface, and 20 feet deep, is carried by easy bends to the bank of the river Ness, and along its northern side to the small loch Doughfour, a distance from Clachnacarry of 6⅓ miles. This lake is about 1⅓ mile in length, and has from five to nine fathoms water, between Clachnacarry and this place. By reason of the steep banks approaching close to the river in three different places, the river's channel was changed. Previous to entering Loch Doughfour, a regulating lock of 170 feet in length, 40 in width, without any rise, is constructed. The entrance from the canal into the small loch, and from it into Loch Ness, have been excavated to a proper depth by a dredging machine.

Loch Ness is a beautiful sheet of water, about 22 miles in length, from one to one-and-a-half miles in breadth, and having a depth varying from 5 to 129 fathoms. In the whole of this extensive lake there is not one rock or bank detached from the shore: and although its general direction is straight, there are several small bays and anchoring places in a moderate depth of water, that is to say, at Urquhart, Invermorrison, and Port Clair, on the north side, and at the bay of Dores and Fyers, and the Horse Shoe, on the south side; there is also good anchorage at each end.

At the south end of Loch Ness stands the fort and village of Fort Augustus; and, on the north side of these, the river Oich falls into Loch Ness. On the northern side of the fort the canal leaves the lake, crosses a part of the glacis, and at the back of the village ascends 40 feet by 5 locks, each 180 feet in length. From thence it passes along the south side of the river Oich to the north-east end of Loch Oich; in this distance, of about five miles, there is one lifting lock, 170 feet in length, 40 in width, and 8 feet rise; and one regulating lock, of the same length and width, but with a rise of 2 feet to 6 inches. The river Oich has at two places been removed into new channels, to make room for the canal. Loch Oich is about five miles in length, its breadth is irregular, on an average about one-fourth of a mile; the entrance to and from it, and a small space in the middle, being shallow, have been deepened by a dredging machine. This lake, which forms the summit level of this navigation, is only 94 feet above the tideway. The river Garry falls into the north-west side: this stream is the drain of the extensive valley of Glengary, and in its source passes through two large lakes, viz. one 10 and the other 6 miles in length: These insure an ample supply of water.

Between the western end of Loch Oich and the eastern end of Loch Lochy, a distance of about 2¼ miles, the surface of the ground is about 20 feet above the surface of Loch Oich, which, with the 20 feet depth of water, requires a cutting of about 40 feet. Near the western extremity of this cutting, there are two locks, one lifting, and another a lifting and regulating lock. The fall from Loch Oich to Loch Lochy, after the latter has been (as intended) raised 12 feet, is about 9 feet 9 inches.

Loch Lochy is about 10½ miles in length, and one in breadth; its general direction is straight; its depth from 5 to 76 fathoms, with various good anchoring places; there is one considerable bay on the north-west side, and at the north-east extremity, a singularly well protected roadstead. In order to avoid rock-cutting at the south-west extremity, the surface of the water in the lake is to be raised 12 feet above its former level; and a new channel has been cut from it, by which the river Lochy is carried into the river Spean.

From Loch Lochy to the tideway at Loch Eil, a distance of about 8 miles, the canal is carried along the north-west side of the river Lochy, over ground of a rugged surface, intersected by one considerable river, and various small streams, all of which require aqueducts to pass the mountain torrents. A small distance from the south-west end of Loch Lochy, there is a regulating lock, 170 feet in length, 40 in width, with a rise of two feet; but the ordinary surface of the lake, after it is raised, will be continued to within one mile of Loch Eil, where there are eight connected locks of 180 feet in length each, and 40 feet wide, and together descending 64 feet: from thence a level is continued to Corpach shore, where there are first two connected locks falling 15 feet, and one single sea-lock falling 7 feet 9 inches, which enters the tideway of Loch Eil. The chamber of this lock was excavated in rock, to afford 20 feet of water at high water of ordinary neap-tides. This connection with the tideway, being to the westward of the general direction of the great valley, and there being good anchorage, an excellent roadstead is obtained.

From this haven, down Loch Eil, to the strait of Ardgower, a distance of about 9 miles, the inlet is about a mile in breadth, in a straight direction. This strait or narrow of Ardgower, of half a mile in width, forms an entrance similar to that of Fort George, on the eastern side of the island. From this station onward south-west, to opposite the eastern extremity of the Sound of Mull, the arm of the sea is named the Linnhe Loch, it opens gradually to about nine miles in width, and is interspersed with islands, the principal (Lismore) being about seven miles in length: they are composed chiefly of limestone, which, when calcined and mixed with clean sand, forms a mortar which hardens under water, and was, on that account, and its vicinity, a most valuable object to the canal works.

The inland navigation, when arrived at the Sound of Mull, falls into the present general track of shipping, which now passes by the Orkneys and Cape Wrath, and is therefore reckoned the western termination of this new line of communication, which not only lessens the distance one half, but is free from the dangers and delays to which the present circuitous one is subjected.

All the most difficult works upon this great inland navigation have been completed, and the whole is in such a state of forwardness as to afford a prospect of the communication between the two seas being opened by the latter end of 1821. The eastern part of it has been navigable for the last three years, with facility and safety. During 1820, upwards of 300 passages have been made. A steam boat has also plied upon it.

Having stated that the navigation by the Caledonian canal extended westward to opposite the island of Mull, and that the general track of shipping continued by the eastern side of Jura Isle, we then find a valuable appendage, named the Crinan canal. This forms a very direct communication with the southern extremity of the arm of the sea called Loch Fine, also the Firth of the Clyde, and opens the Greenock and Glasgow markets to the north-west parts of Scotland. By consulting the map of that country, it will be seen that this canal saves the doubling the Mull of Cantyre, a slip of land about 60 miles in length; the passing round which, besides the great distance, requires two winds, and is also much exposed to the north-west gales, so frequent and violent in this quarter.

Besides being an accommodation to the Clyde traders and fishers, the coasting vessels from Liverpool, and all Ireland, prefer always in bad weather to pass up the eastern side of the Cantyre land, and cross by the Crinan canal into the before-mentioned general track, near the north-east end of the island of Jura. Thus, it will be evident, that by means of this Crinan canal, and the inland navigation to Inverness, &c. vessels will pass by a well sheltered course from the Irish Channel, quite to the North Sea, opposite to the entrance into the Baltic.

The length of the Crinan canal is nine miles; the summit is only 62 feet above the tideway, and is passed by 15 locks, each 96 feet in length, and 24 in breadth. During the last two years, a steam-boat has passed *regularly along it in its way* from Glasgow to Fort William.

From this brief description, it is evident that the artificial still water navigations in Scotland are but few, and of small extent; and from the generally mountainous and pastoral nature of the country, it is not probable that many more can be required; more especially as it is singularly well accommodated by the numerous arms of the sea, which penetrate deeply into this narrow country; and as the Firths of Forth, Tay, Dee, Clyde, Nith, and Solway, afford useful navigations and havens.

Ireland.

It has been said that the first idea of improving river navigation in Ireland is due to the enlightened administration of the unfortunate Stafford, incited probably by what had been done in the Low Countries; but we find nothing in the history of the Irish Parliament on the subject, until the earlier part of the last century. The general flatness of the country, and the abundance of lakes, waters, and morasses, are very favourable for creating and extending inland navigation.

In the first Parliament of Anne, on the 29th September, 1703, a committee was appointed to prepare heads of a bill for making the river Shannon navigable from the city of Limerick to James Town in the county of Leitrim; also for the rivers Barrow and Boyne, and a canal from Lough Neagh to Newry. On the 8th November, the committee reported, that the scheme for the latter was practicable and beneficial, and might be constructed for 20 ton lighters for 20,000*l*. The surveys were made by Captain Francis Nevil, collector of Armagh; but it does not appear that any farther steps were taken at this time.

In 1709, the heads of a bill were brought in for making the Shannon navigable from Limerick to Carrick; also a petition for the Newry canal, for which a bill was passed; likewise a petition for making the Lim navigable from Clonmel to Thurless; and another petition for removing the rocks at Portnaw, in the river Bann; also for making the river Barrow navigable; but no progress was made in these matters for some years. In 1715, George Frizell, Henry Crosdale, and others, having undertaken to make the Shannon navigable, an act for that purpose passed, and a general law was established, for undertakings of the same kind, which may be considered the parent of the inland navigation of Ireland. It is entitled, "An act to encourage the draining and improving the bogs and unprofitable low grounds, and for easing and dispatching the inland carriage and conveyance of goods from the one part to another within this kingdom." The undertakers were allowed a toll of 2d. per cwt. for every ten miles of 12 furlongs, and 3d. for each passenger. Gross timber for building, rough stone, bricks, lime, to pay only one half toll. The members of parliament and justices were appointed commissioners, and for other rivers than the Shannon, with powers to appoint undertakers; and the following improvements were partly proceeded with:

1. From Dublin, by the rivers Liffey, Rye, Boyne, Mungagh, and Brusna, to Banagher on the Shannon. Two canals have since been carried in nearly this direction, viz. the Grand Canal towards the lower, and the Royal Canal towards the upper, parts of the river Shannon.
2. The river Barrow, and a canal from thence to join the Grand Canal at Munroe in the Bog of Allen.
3. The rivers Glyn and Bann, from Newry to Coleraine, which has been made to Lough Neagh under the name of the Newry Canal.
4. The Nore and Brosna, from New Ross to the Grand Canal near the Shannon.
5. The Liffey and Greece, from Dublin by Kilcullen, to Carlow. A branch of the Grand Canal has been carried nearly to Kilcullen, known by the name of the Kildare Canal.
6. The Blackwater, from Youghall to Newmarket, (only effected as far as Lismore.)
7. The Foyle, Findberg, and Mourne, from Derry to Omagh, (effected to Strabane.)

8. The Earn, above Lough Earn, (unattempted.)
9. The Maigne, from Limerick to Cork, (do.)
10. The Boyne, from Drogheda to the Grand Canal; it has been rendered navigable to Navan.
11. A line from Sligo to the Shannon, at Carrick, (unattempted.)
12. A line connecting the Lakes Corril and Mask at May river, from Galway to Killala, (unattempted.)
13. The Slaney, from Winford to Baltingless, (unattempted.)
14. The Suir, from Waterford to Thurless; some improvements have been effected, and a towing path made to Clonmell.
15. A line from Galway to the Shannon at Portumna, (unattempted.)
16. The River Inny, from Lough Shillin to the Shannon, (unattempted.)
17. The River Luck, from Castlerea to the Shannon, (unattempted.)
18. The Lee, from Cork to Macroome; some locks were made, but to no purpose.
19. The Banden, from Kinsale to Dummanery, (surveys only were made.)
20. The Leune, from Rosscastle to Castlemain harbour, (unattempted.)

The Laggan navigation is unnoticed in this act, and it does not appear that for 14 years afterwards, any effectual progress was made in consequence of these undertakings. For, in an act in 1729, it is stated, that the said commissioners having only power to contract with undertakers for carrying on the said works at their own private expense, the great charge hath discouraged private persons; and where encouraging tillage, and employing the poor, will be of great benefit, and it is reasonable and fit that works of such public benefit, should be carried on at the charge of the kingdom by some public fund, &c. &c.

The Lord Lieutenant, four Archbishops, Lord Chancellor, and the Speaker of the House of Commons, with 20 others persons, for each of the four provinces, were appointed commissioners, and from 25 Geo. II. made a corporate body, with extended powers for carrying on the inland navigation of Ireland; and, for a fund, a duty was imposed on private carriages of 20s. per annum for four-wheeled carriages, and 5s. for two-wheeled carriages; on cards, 6d. if made in the kingdom, and 1s. if imported; on dice, 5s. per pair; and on wrought plate, 6d. per oz. troy weight. The amount of these, to the year 1735, was 3000*l.* per annum; to 1740, was 4000*l.*; and to 1750. was 6000*l.*

By the petition of the commissioners in 1758, it appears, that for 19 years, the whole fund was applied to the canal from Newry to the Tyrone collieries. In 1749, there was expended 58,400*l.* 1*s.* 1*d.*; and though the works were imperfect, the savings on the fund was 9393*l.* 10*s.* 1*d.* In 1749, they engaged in other works on the rivers Boyne and Shannon, by which, in 1758, they had expended the whole fund, amounting nearly to 140,000*l.*

In 1749, the House of Commons renewed the expiring duties on carriages, &c. and granted a further supply of 4000*l.* per annum from 1751. In 1753, petitions were presented from Belfast, Lisburn, Hillsborough, Killala, and Moira, for opening a river and canal navigation by the river Laggan to Lough Neagh, estimated at 26,000*l.* In the 27 Geo II. an act was passed to open a navigation between Belfast and Lough Neagh; and 1d. per gallon on beer, and 4d. per gallon on spirits, was levied on the district of Lisburn for eleven years for said navigation.

In 1755–6, many petitions were presented from other districts, but few had the independence of the north, to propose local taxation.

The city of Cork petitioned to make the river Lee navigable; Kilkenny for the river Nore; Newry for an improvement in its river below the quays; and Belfast for additional aid for the Laggan navigation. Petitions were also presented for rendering the Blackwater navigable 40 miles to the collieries of Dromagh: the Suir, from Clonmel to Waterford; the Bann, from Lough Neagh to Coleraine.

The Tillage Committee reporting that these various inland navigations were the most effectual means to increase tillage, especially from Dublin to the Shannon, the lines of the present Grand and Royal canals were then in agitation, but the sum of 20,000*l.* voted to the corporation for inland navigation for a canal to the Shannon, was directed to be applied to the line on the south of the city, now the Grand Canal. Exclusive of the before-mentioned sum, there was granted for river navigations and harbours, the further sum of 65,000*l.* and this was besides the formerly stated tillage dues. The national revenue, about this time, did not exceed half a million.

Mr. Thomas Orme was the engineer employed to examine most of these lines of navigation, as appears by his petitions to the House of Commons for remuneration.

The system of promoting the inland navigation, and other public works, by grants of public money, was continued for many years by the Irish Parliament, and has been the leading principle on which they have been undertaken.

In 1767, the system of management was in some measure changed; for, in appropriating 6000*l.* towards improving the Lower Shannon, it was only granted under condition of 10,000*l.* being subscribed by the company, and 20 per cent. of that paid. An act of Geo. III. incorporated the Limerick Company, which still exists. William Chapman was their engineer. These works, by the aid of the directors general, are completed; but little benefit has been derived from them.

On renewing, in 1771, the duties appropriated to the purposes of inland navigation, for seven years, it is stated, 11 & 12 Geo. II. c. 4. sect. 3. that "Whereas the method of carrying on inland navigation altogether at the expense of the public, may be found, in many instances, inconvenient, and attended with great delay; and the improvement of the kingdom may be much promoted, if private subscribers could be found, who would carry on such works at their own expense, and it would be reasonable to give such subscribers encouragement so to do." The corporation are empowered to transfer the property to such a company, and to advance one sixth part of the expense for completion, out of the duties aforesaid, the new company paying the other five-sixths. These tillage duties amounted, at this time, to 8500*l.* per annum, and Parliament voted 1000*l.* more. The corporation were also empowered to build a lock across the Shannon, at Limerick, and levy a tonnage upon ships for its support.

The 11 & 12 Geo. III. c. 31. empowers certain persons to complete the Grand Canal, to make cuts to towns and rivers, and vests in them the works already made, but requires of them to subscribe 60 000*l.* with any necessary additions, not exceeding 150 000*l* and empowers them to levy a tonnage duty of 4*d.* per mile, and 2*d.* per lock. By the 17 & 18 Geo. III. c. 29. two-thirds of the bounty on corn, brought by inland carriage to Dublin, was given to that brought partly by canals. This bounty somewhat exceeded the price of land carriage.

The corporation for inland navigation formed a body much too numerous for efficient operations, and the business fell into a state which called loudly for reform. On renewing their powers in 1798, it appeared they had overdrawn their funds to the extent of 20,139*l.*; these powers were therefore restricted to paying the salaries and accidental breaches only, until all just debts were satisfied. Notwithstanding this, in 1784, their debts had increased to 26,284*l.* By 27 Geo. III. c. 30. the corporation was dissolved, and their debts provided for by debentures at 4 per cent. The several navigations which had been undertaken by the corporation were vested in different bodies of local commissioners, viz. the Newry Navigation, the Boyne, the Barrow, the Shannon above Kilaloe, and the Tyrone colliery canal.

By the resolution of the House of Commons in May 1788, it appears that the Grand Canal was now completed to the river Barrow at Monasterevan, and it was thought most adviseable to expend the navigation funds in the first place to the extent of 10,000*l.* on the improvement of the Barrow and the Suir, and to employ engineers to ascertain the best northern and southern lines from the Grand canal to the Shannon.

The Limerick Navigation Company not being able to complete their works, it was resolved to grant this and others in a similar situation to new companies of subscribers, who might be willing to engage in them, on being furnished one-sixth part of the expense by the public; and 7000*l.* a year were voted for the purposes of inland navigation.

In the same year, (1788,) local duties were applied for by Newry and Drogheda, for procuring 1000*l.* per annum towards their respective harbour channels. In this year, also, it appears that 241,285*l.* had been expended upon the Grand Canal, besides interest and treasury warrants unpaid. They complain that the aid of one-sixth is too small for encouragement of canals in a country where mines and manufactures do not exist. In 1789, the House of Commons resolved to advance one-third of the expense of any new undertaking of this kind; and as the tillage duties were insufficient, authority was given to issue debentures, bearing interest at 4 per cent. to the extent of 200,000*l.* but not to exceed 25,000*l.* in one year.

The schemes which, in consequence of this liberal provision, were the following:

The Barrow to be completed . .	£20,000	0	0
The Shannon below Kilaloe . .	8,300	0	0
The Grand Canal to the Shannon .	57,100	0	0
Do. for junction with the Liffy . .	10,000	0	0
The Royal Canal from Dublin to the Upper Shannon at Tormenbarry .	66,000	0	0
Boyne from Drogheda to Trim .	12,500	0	0
Newry Navigation . . .	4,000	0	0
County Kildare Canal to Naas .	2,400	0	0
Do. from Naas to Kilcullen . .	3,300	0	0
Lough Earne Canal . . .	5,100	0	0
	£188,700	0	0

And by the 31 Geo. III. the additional sum of 11,300*l.* was appropriated, viz.

For the Grand Canal for the junction between Alky and Barrow .	£2,120	12	6
Canal towards collieries . .	4,370	2	4
Do. to Ballycider . . .	1,204	12	4
Marquis of Abercorn for Foyle Navigation tu Strathbane . . .	3,703	12	0
	£11,398	19	2
Grand Canal for Bocks . .	22,000	0	0

By the reports of the Commissioners of Account in 1790, it appears, that besides all that had been expended by the several companies who had undertaken the works, that the corporation for promoting inland navigation had disbursed

Of public grants . . .	L227,669	2	1½
Of income from duties . .	359,868	9	6¼

From this period, to 1800, various other grants were made upon the same terms, but no one scheme of navigation was adopted. The two great canal companies, in the course of their negotiations with government, had been induced to undertake an expensive system of wet docks in Dublin, which greatly embarrassed their funds, without much prospect of reimbursement.

On the eve of the Union, in 1800, a sum of 500,000*l.* was granted by the 40 Geo. III. c. 51. for inland navigation generally; for the improvement of the port of Dublin, and for one or more lines of communication from Dublin to the Shannon, and for rendering that river navigable from Lough Allen to the sea. By this act, the Lord Lieutenant is empowered to appoint five directors, with salaries not exceeding 500*l.* each, for managing all works of inland navigation to which public money is applied. And it was enacted, that no new canal should levy a higher toll than 1*d.* per ton per mile on corn, flour, potatoes, sand, lime, fuel, or manure; 2*d.* per ton on other goods; and 3*d.* per passenger. In carrying the act creating this department into effect, the following grants had been made, up to 1812:

To the Royal Canal Company .	£95,866	7	10
Barrow Navigation . .	47,500	0	0
Grand Canal Company for the Shannon between Lough Ree and Lough Derg .	54,634	18	7
For improving the Port of Dublin	15,000	0	0
	£213,001	6	5

Besides which, the directors-general have themselves expended, including tolls, up to that date.

Dublin harbour, for plans, &c. .	£7,250	16	7½
Newry Navigation . . .	54,516	19	0
Tyrone and Magheny Canals. .	21,715	19	10
Limerick Navigation to Killaloe .	53,639	16	4
Upper Shannon Navigation . .	7,168	17	1
	£144,292	8	10½
And the expense of their establishment for 12 years . . .	66,504	9	5

But the purchasing a reduction of tolls to so low rates, as has been done by the directors-general, appears injudicious, for while the public must, in taxes or some other shape, pay for this reduction, the resources of the canal company are so much diminished, as totally to destroy any prospect of profit, and all spirit of adventure. Accordingly, since the year 1800, there has not a single new canal been undertaken, and the two greatest are in very embarrassed circumstances.

Besides these several applications of their funds, the directors-general have, since 1810, had various parts of the country examined by their engineers, to ascertain where canals were practicable and advantageous; and surveys have been made between the Shannon, Barrow, Suir, and grand canal. Similar researches have been made towards Lough Earne and Lough Neagh, and towards the improvement of the Port of Dublin. Various minor lines of navigation have likewise been pointed out in consequence of the parliamentary survey of the bogs. And it may now perhaps be said, that, with the exception of Holland, a more perfect knowledge of the levels and waters of Ireland has been obtained, than of any other country in Europe.

Having now given a general view of the rise and progress of inland navigation in Ireland, we proceed briefly to describe the present state of each navigation, whether canal, lake, or navigable river, as they occur in alphabetical order.

The Bandon River, in the county of Cork, is navigable from the Port of Kinsale to within two miles of Bandon. A canal from thence to Dunmanway has been projected.

The Bann River, rises in the Mourne mountains in the county of Down, and passing northward, falls into Lough Neagh; near Port-a-down, it is joined by the Newry canal, and is navigated from thence by boats of 40 or 50 tons, for about 9 miles to the lake.

The outlet of Lough Neagh is called the lower Bann, and falls into the sea at Coleraine: this is yet unnavigable.

The Barrow rises in the northern part of the Slieve Bloom Mountains, running eastward to Monasterevan, where it is crossed by a branch of the Grand Canal; from thence that canal passes southward, nearly parallel to the river, and joins it at Athy. From Athy Bridge, in the county of Kildare, the river has been rendered navigable to the tideway at the rocks, called the scars, below St. Mallin's, in the county of Carlow, a distance of about 34 Irish or 43 English miles. The total fall is 172 feet; in 1800, there were 14 old and new locks, the navigation is chiefly in the bed of the river, the total extent of the new cuts 5 miles, their breadth 27 feet at bottom, and 42 at water surface, with 5 feet water. Ten of the locks are 80 feet long and 16 wide; the others 69 by 14 feet.

This is one of the most valuable communications in Ireland, that is, from Dublin through a fertile country, to the Rivers Nore and Suir, and to the ports of Waterford and Ross. The annual amount of tonnage, about 40,000 tons, tolls 4,250*l.* from grain, potatoes, lime, manure, coal and culm from the Kilkenny collieries, Carlow flags, building materials, &c.

The Black-water, a river in the county of Cork, rising on the borders of Kerry and Limerick, and flowing eastward into the Atlantic at Youghall. It admits vessels of 300 tons over the bar. Sloops pass to Dromore, about 8 miles up the Bridge, within two miles of Tallagh. A navigable canal has been made by the Duke of Devonshire, from Cappoquin to Lismore, 3 miles. Three miles of canal, and two locks of large dimensions, were made above Mallow, but nothing farther has been effected

The Black-water is also the name of a river in the counties of Tyrone and Armagh, forming part of the colliery canal, or Tyrone navigation.

The Boyne. This river rises in the Bog of Allen, in the central plains of Leinster, and flows north-east into the Irish sea, at Drogheda. By the care which has been taken to deepen the mouth of its channel, across the sandy bay of Drogheda, vessels of considerable burthen ascend three miles to that town, where the Boyne navigation commences, and continues for 9 miles, chiefly in the bed of the river to Slane, thence 6 miles of still water navigation to Navan, and 7 more from Navan to Trim. The chief articles of trade are, coals, slates, timber, iron, salt, &c. upwards; and grain, yarn, and linen, downwards. The total ascent from Navan to Trim is 189 feet. Width of cuts from 16 to 25 at bottom, and from 30 to 49 at top water, which is 5 feet deep. The locks vary from 80 to 100 feet in length; the breadth is 15 feet.

The Foyle river is formed by the union of several streams from the counties of Tyrone and Donnegal, at Strabane; its course is northwards into the bay, called Lough Foyle, below Londonderry. The river is naturally navigable for 7 miles, by Londonderry to St. Johnston, thence a navigation was made by the Marquis of Abercorn for three miles to Strabane.

The Fergus, is an arm of the Shannon into the county of Clare; it has been rendered navigable to Ennis, the county town, by boats which ply on the Shannon.

The Grand Canal and its branches. It commences from the river Liffey, near its mouth, where there is a floating dock, which could contain above 400 ships, with 16 feet water; it has three entrance locks, and three graving docks. From thence the canal proceeds by the south side of the city of Dublin, to James Street harbour, and from thence westward for 62½ Irish miles through the counties of Dublin, Kildare, and King's county, to the river Shannon, near Banagher, with branches to the Barrow at Athy, and to various reservoirs and towns, in detail as follows:

The circular line to St. James's Street, . .	3 miles.
From James's Street Main Trunk to Lawton, .	21
Main Trunk from Lawton to the Shannon, .	44½
Branch from Lawton to the River Barrow, .	21
Do. to Miltoun Reservoir, ...	7
Do. at Bog of Allen and Foranfore Reservoir,	3
Do. to Edenderry, ...	1
The Kildare Canal from Sallins to Naas and Corbally,	6

The commodities carried on this canal are, flour, grain, potatoes, turf, Kilkenney coal, manure, building materials, and merchandise. The annual revenue, in 1812, was 79,500*l.*; the expense of establishment and maintenance, about 21,920*l.* In 1813, the revenue was 90,000*l.* but since the peace it has greatly diminished. The summit level is 240 feet above the sea, and 160 above the Shannon; the width is 25 feet at bottom, and 40 feet at the water surface; depth, 5 feet on the lock sills, and 6 feet in the canal. There are 5 double, and 29 single locks, between Dublin and Tullamore; 10 from thence to the Shannon. Length of locks, 70 feet, width, 14½ feet, average rise and fall, 9 feet.

On the Barrow line, from Lowton to Athy, there are 10 single, and 2 double locks. The portion of this canal adjacent to Dublin, is of great width, laid out in long straight lines, and planted with trees along each side; the too frequent adherence to these straight lines has frequently involved unnecessary expense, by cuttings and embankings. The only aqueduct of note is about 15 miles from Dublin, where the canal crosses the Liffey at Monasterevan, the Barrow line locks down into the river, and crosses the stream to a regulating lock on the opposite side.

From accounts printed by the House of Commons in 1812, it appears there had been expended by the Grand Canal company, for the navigation, only 966,364*l.* 13*s.* 9*d.* In 1806, the directors-general gave this company 54,634*l.* 18*s.* 7*d.* to complete the navigation of that part of the Shannon river between Lough Derg and Lough Ree, to have 6 feet water at all seasons. These works have been completed, but without track-way, at an expense of 30,222*l.* 19*s.* 3*d.* beyond the sum advanced to the company. The tolls are more than 1d. per ton, per mile, in this part of the Shannon.

The Cermlin and Inny rivers, in the county of Longford, falling into the Shannon, are sluggish, and have few obstructions; they have hitherto not been used as navigations.

The Laggan navigation extends from the tideway at Belfast, partly in the river passing Lisburne, Hillsborough and Moira, into Lough Neal; total length, 16 Irish miles; its origin and progress have already been narrated.

The river Lec, in the county of Cork, is navigable for masted vessels of 200 tons, to the old bridges of Cork, and for barges about a mile farther, to the head of the island, to the Mill Weirs. The only attempt to extend the navigation was the formation of one lock to pass this weir, and a second for another weir, about a mile higher. The project was abandoned, and the locks are now filled up.

The Lane and Main, in the county of Kerry, unite and fall into the head of Dingle bay; they admit sloops to Killeglin and Castlemain; and it has been proposed to render the Lane navigable into the lake of Killarney.

The Liffey rises in the Wicklow mountains, and falling into the sea at Dublin, forms the harbour of that city. It is navigable for three miles, to the upper end of the city, and is provided on each side with excellent quay walls. With a view to regulate and deepen its channel across the extensive strand of Dublin bay, a pier has been built for three miles in length from the shore; having, in near the middle of its length, a small fort, called the Pigeon House, with a dock for the Holyhead packets, and an elegant lighthouse at the extremity; the channel is regularly dredged by lighters. These works have, for upwards of a century, been carried on under the direction of the Ballast Board; but notwithstanding the immense sums which have been expended, the harbour of Dublin is still found to be very imperfect, and projects have been formed for making artificial harbours, either within or without the bay, to which vessels may safely resort at all times.

The harbour of Houth, originally proposed as the packet station, has been enlarged, with the view of also accommodating trading vessels, and is now nearly completed, at an expense of about 300,000*l.* granted by parliament; but this great work, not appearing to be well calculated for the trade of Dublin, another harbour has been begun within the bay at Dunleary, on the south side, the expense of which will probably exceed that of Houth, and it is supposed a ship canal may, at some future time, be made from it to the city, about 5 miles.

Lough Earne, a lake in the county of Fermanagh, is about 30 miles in length. The river Earne rises in Lough Gounah, on the borders of Longford, and, passing through the county of Cavan, becomes navigable below Belturbet, where it enters Lough Earne. Leaving it again at Enniskillen, the navigation is obstructed by weirs, but below the town it again gradually expands to the breadth of 10 miles. Near Belleek, the navigation terminates at the bottom of a fall, or salmon leap; thence the river passes rapidly for five miles to Bally Shannon, where it falls into Donnegal bay. It has been several times proposed to complete the navigation from Belturbet to Bally Shannon, and for that purpose a company was incorporated in 1790; but, after expending several thousand pounds, the project was abandoned.

The lake and river of this name are navigable from Galway westward, for nearly 30 miles, for boats carrying about 14 tons. The chief trade is turf, lime, and grain, into Galway.

The Maig is a branch of the Shannon, in the county of Limerick; it is navigable for the Shannon boats to near Adare.

Moy, in the county of Mayo, is navigable from Killala bay to Ballina.

The Newry navigation, the first executed in Ireland, extends, 1st. From the tideway at Fathom, 2½ miles, to Newry, and admits vessels drawing 9 or 10 feet of water, having a sea lock at each end, 120 feet by 22, and 17 feet deep.

2. From Newry to the navigable river Bann, 12 miles, is a canal for barges of 40 to 60 tons; it has 30 feet water at the surface, and 5 feet deep. There are 13 locks, 60 feet by 15. The summit is here 65 feet above the sea, and 22 above Lough Neagh.

3. The river Bann, for 9 miles into Lough Neagh, which is navigable 13 miles, and 8 broad, and which also communicates with Belfast by the Laggan navigation, with the Tyrone collieries by the Black-water river, and with the town of Antrim by the Antrim river.

The chief trade on the Newry canal, is importing bleaching materials, flax seed, iron, timber, and foreign produce from Newry; and exporting agricultural produce, yarn, linen, and coal.

The Nore river is a branch of the Barrow. It rises in the Slieve Bloom, passes Kilkenny, becomes navigable for barges at Thomastown, and for sea vessels at Inistogue, and near New Ross falls into the Barrow.

The Royal canal extends from Dublin westward to the Shannon, nearly parallel to the Grand canal, seldom 10 miles distant. The navigation commences on the north side of the Liffey, by a sea lock 116 feet by 27 feet, with 14½ feet high water; there is next a floating dock, to contain 25 sail of ships: there is also a second dock, now incomplete; from thence the canal has 6 feet water, 24 feet bottom, and 44 width at surface; in 1½ mile, it rises 62 feet, by 4 locks, to the broad-stone level, where there is a large harbour for the use of the city. From thence, in 18½ miles, there is a farther rise of 175 feet by 14 locks. The level is then 16 miles in length; then 8 locks, in 5½ miles, rise 70 feet to the summit level, which is 307 above the sea; this summit is 12 miles in length to Coolnahay, communicating by a navigable river at Mullingar, with Lough Owell, which is the chief reservoir for this navigation. From Coolnahay, the canal descends by 15 locks, in 22 miles, to the Shannon at Tarmonbarry, in the county of Longford. Total length, 68 Irish miles. The Shannon is navigable from this point 27 miles.

The Shannon is the largest river in Ireland. It rises in Lough Allen, in the county of Leitrim, running southward 100 miles to Limerick, where it enters the tide-way, and from thence westward 50 miles to the Atlantic Ocean. In its course, this river expands into a variety of wide lakes, of which Lough Rec and Lough Derg are the most remarkable; it is joined by the Royal Canal at Tarmonbarry, by the Grand Canal at Shannon harbour, near Banagher, and has been rendered navigable through the greatest part of its course. Round Lough Allen are valuable mines of iron-stone and coal. Near Lough Derg are quarries of excellent slate, and although much of the immediate bank of the Shannon is turf-bog, the course of the river is, in general, through a fertile country.

1st, The Shannon is navigable for ships of 300 tons, to Limerick, where the Limerick navigation commences, and proceeds partly in the river, and partly by canals, to pass the rapids, 12 miles to Killaloe, at the entrance of

Lough Derg. There are 11 locks on this navigation, and a track-way for the whole length. There are capstans and warping chains at O'Brien's bridge, and various lesser works. The whole suited to vessels frequenting the Grand Canal.

2d, From Killaloe Lough Derg is navigable by the sail and oar, 20 Irish miles (or 25½ English) to Portumna. At the upper end of Lough Derg, the Shannon becomes the property of the Grand Canal for 40 Irish miles, as far as Lough Ree, above Athlone; and, to facilitate its navigation, there are four locks of large dimensions, with side-cuts at the bridges of Athlone, Shannon bridges, Banagher, and Cloghan, but there is no tracking path.

3d, Above Athlone, we enter Lough Ree, 13 Irish miles in length, navigable by sail and oar. Above this lake, at Lanesborough, commences the Upper Shannon navigation, which is as yet public property, and extends 26 Irish (equal to 33 English) miles to near Leitrim, fit for boats of four feet water, leaving only 7 miles unnavigable to Lough Allen, which is 7 Irish miles in length. The vessels using this navigation generally carry 30 to 40 tons, are worked with a square sail, and have four hands on board. There are side-cuts at the bridges of Lanesborough, Tarmonbarry, Rooskey, Jamestown, &c. The rest of the navigation being in wide reaches of the river, with shallow shores, and without track-ways, is necessarily very imperfect; but, by the late invention of the steam boats, most of the difficulties attending the river and lake navigation may be obviated.

The Slaney river rises among the Wicklow mountains, and, running southwards, falls into the channel at Wexford; it is navigable for barges 15 miles to Enniscorthy.

The Suir river, a branch of the Barrow, rises from the Keeper Mountains, and the northern part of the range of Slieve Bloom, in the county of Tipperary, and running southwards, passes Thurles, Cashel, and Cahir; afterwards turning eastward, it becomes navigable for barges at Clonmell, for sloops at Carrick, and the largest sea vessels lie afloat in 40 feet water, at the town of Waterford, five miles below which it joins the united Nore and Barrow, and thence turning southward for 11 miles, forms Waterford harbour, and joins the Atlantic; but, with the exception of a towing path from Carrick to Clonmell, no remarkable improvement has been made upon this river.

Below Waterford, the Suir divides into two branches, embracing the little island. Of these, that called the King's Channel, though deep, is circuitous and dangerous. The other, called the Ford, is more direct, though shallow. An act was lately obtained for the purpose of deepening this ford, and otherwise improving the navigation of the Suir, and levying duties on the ships for defraying the expense. A steam-dredging engine has been constructed, and the work is now in progress. There are, however, other bars in the haven, on which there is not depth at low water of more than 12 or 13 feet.

The Tyrone colliery canal extends from Coal Island, in the county of Tyrone, three miles to the Blackwater river, and from thence, by a short cut across the Isthmus of Maghery, into Lough Neagh, thereby avoiding the bar of the Blackwater, upon which there is only about 22 inches of water in summer. The vessels using this canal are the same as those on the Newry and Laggan navigation. There are eight locks to the Colliery basin, from whence a wooden railway extends to the mines. This canal is chiefly remarkable, as being the first in this country, on which inclined planes and railways were employed to unite canal ponds of very different levels. The merit of the attempt is due to Mr. Davis Dukart, who had been an engineer in the Sardinian service, and adopted the idea from the rolling bridges used on the continent; but, after taking the opinion of Messrs. Smeaton and Jessop, these works could not be completed, from the want of funds, and the death of the engineer, and a common rail-road has been adopted.

Such has been the rise and progress of the inland navigations of Ireland, which are chiefly remarkable for being undertaken, not to facilitate any existing trade, or to form a short passage instead of a circuitous navigation, nor even for the export of inland mines, for the two or three solitary instances where this was attempted have been unsuccessful; but they have been undertaken chiefly to promote agriculture in the fertile districts of the interior, to create a trade where none had previously existed, and to furnish employment for the poor. The success, in this way, has been wonderful; and, though the adventurers have not yet been repaid, and perhaps never will, if we except those who have advanced capital by way of loan, to whom the interest has been paid with great regularity, the benefit to the public and landed property of the kingdom has been great and manifest. The nation has been saved the payment of a bounty of 100,000*l.* per annum for bringing corn to Dublin; for, in place of this being the case, that city has now become one of the first corn ports of Europe: and Ireland, in general, which, half a century ago, imported corn to the value of half a million per annum, has now a surplus produce in that article to the value of four millions per annum, while the whole amount of the expenditure, whether on public or private works of navigation, even including the interest paid on loans, hardly amounts to three millions.

America.

In treating of the inland navigation of North America, we must describe lakes, rivers, and projects for artificial canals.

This continent is singularly favoured by nature in the immense extent and ramification of its navigable waters. Its great central plain is occupied, in the north, by the lakes of Canada, the largest body of fresh water on the globe, the outlet of which forms the great river St. Lawrence, running to the north-east. The south and west are drained to the Gulph of Mexico by the still greater river Mississippi, which, with its various branches, is navigable in most places nearly to their sources.

The Mississippi, including the Missouri, (which articles see) the Ohio, and all its other branches, may generally be stated as affording a navigation through a triangle of country, of which the line from New Orleans to above Pittsburg on the Ohio, 1000 miles, may be reckoned the base, and the other sides 1600 miles each; so that the basin of navigation is nearly one half greater than that of the Volga. The comparative slopes of these basins are also similar: the fall from the Vishnie Voloshok, to the lake Ladoga, is, (according to Captain Perry) 568 feet; the height of Lake Erie, above the tide-water in the Hudson is known, by the levels of the proposed Grand New York Canal, to be 565 feet, and we may reasonably suppose the slope of the St. Lawrence through Detroit, and the Hudson between Albany and New York, to be much the same with that of the Neva from Lake Ladoga to the Baltic. Now the waters of the Lake Michigan, when high, are said to back into the head waters of the Illinois, a branch of the Mississippi, and admit boats to pass from the one to the other; so that these head waters are, in all probability, very nearly at the same level as those of the Twer branch of the Volga. From this gentle inclination, and the very winding course of the rivers, which are in general two or three times longer than the direct distance, the branches of the Mississippi are, for the most part, navigable for some kind of craft, almost to their heads. Vessels of 300 tons ascend as high as Natchez, more than 400 miles from the sea; but their progress, owing to the velocity of the current, is so very slow, that the passage from the sea to New Orleans is from 5 to 30 days, whilst the descent, of the same distance, does not exceed 12 or 14 hours. The usual progress of a boat up the river is about five leagues per day. But the steam-vessels (of which there are now upwards of one hundred on the Ohio and Mississippi) sail against the stream at the rate of sixty miles a-day, when heavily laden. The current down the Mississippi is from three to four miles an hour.[*] Between Arkansas and the Delta, the current is one-third less, and thence to the outlet it is diminished by one half.

The main river is navigable uninterruptedly, as high as the falls of St. Anthony, through fifteen degrees of latitude, and measuring by the stream about 2000 miles. The chief branch is the Missouri, which joins St. Louis, 15 miles above by water, and adds a navigation of about 2500 miles along the main stream. Its chief branches are, the Osage, Grand River Kanses, Platte, Yellow Stone rivers, each of which may be said to add from 500 to 1000 miles of navigation, and there are many smaller. The other chief branches of the Mississippi, above the Missouri, are the Illinois, River Des Moines, Rock river, and St. Peter's, to each of which we may allow 4 to 500 miles of navigation; and from some of which there are only short portages to the lakes of Upper Canada.

But by far the most important branch is the Ohio, as affording a direct communication with the eastern states, and being already the channel of a great inland trade. The Monongahela and the Allegany rivers unite near Pittsburg, and form a great river, the Ohio, which flows 948 miles to join the Mississippi in lat. 37°; beside others of lesser note, the Ohio receives from the N. W. or right side, in descending from the junction of the Allegany and Monongahela, Big Beaver, Muskingum, Hockhocking, Scioto, Little Miami, Great Miami, and Wabash; from the south-east or left side, comes in the Little Kenhawa, Great Kenhawa, Big Sandy, Licking, Kentucky, Salt Greene, Cumberland, and Tennessee. The Allegany branch, which rises in the state of Pennsylvania, is navigable a distance of 270 miles, and by French creek has a direct communication towards lake Erie. Its outlet is 350 yards in width, the mean velocity is a mile and a half per hour, but when the waters are high it is four miles. The Monongahela is navigable, except at low water, in dry seasons, to Morgantown, for boats 100 miles from its mouth; and during the swell of the waters in spring and autumn, ships of 400 tons may enter, and proceed some distance from its mouth, which is 440 yards in width; the mean velocity of the current is two miles per hour, excepting during the period of the swell of the water in Spring and Autumn, when it is from three to four.

The Muskingum, or Elk's Eye, of which the outlet is 25 yards in width, is navigable for small boats, through its whole course, to its head in a small lake, a distance of 150 miles; and large boats ascend to the Three Legs, 110 miles from its mouth. Great Hockhocking, which unites with it 215 miles from Pittsburg, is navigable to the distance of 70 miles, from its source to the Cayhaqu River, which communicates with lake Erie; there is but a mile of portage. The great Kanhawa rises in North Carolina, in the easternmost ridge of the Allegany mountains, and joins the Ohio 283 miles below Pittsburg. The navigation is good for the distance of ten miles; thence to the Falls, 60 miles, the stream is rapid, and the passage of boats is interrupted by a cataract called the Great Falls, 70 miles distant from its mouth, which is 500 yards in width. From the Great Kanhawa to James' River, which falls into the Chesapeake bay, the portage is but a few miles. Great Sandy river is navigable to Cumberland Mountain. The Big Scioto, which falls in under the parallel of 38° 43′, at the distance of 330 miles from Pittsburg, is navigable nearly 200 miles, to a point from which the portage is but four miles to Sandusky river of Lake Erie. Salt river, which discharges itself on the south-east side 20 miles from the rapids, by an outlet 150 yards in width, is navigable thence to the distance of 60 miles. The Great Miami, or Rocky river, which enters 435 miles from Pittsburg, is, at the distance of 120 miles, navigable for loaded canoes. Licking river, which enters 422 miles from Pittsburg, is navigable to the distance of 70 miles from its mouth. Kentucky river, which enters 496 miles from Pittsburg, is navigable in high water for loaded boats to the distance of 160 miles from its mouth. Cumberland enters the Ohio 883, and Tennessee 896, below Pittsburg; both those great branches are navigable many hundred miles above their mouths. Buffalo river is navigable for boats of seven tons for 150 miles. The Wabash, which joins the Ohio 810 miles below Fort Pitt, lat. 37° 41′, is navigable for small boats drawing three feet water to Ouitanon, a distance of 412 miles. The Cumberland, 948, is navigable, for ships of 3 or 400 tons, two hundred miles above Nashville. The Tennessee, the largest branch of the Ohio, rises in the Iron Mountains, on the borders of Carolina and Georgia, and passes across the Cumberland Ridge, where its bed is confined within the breadth of 70 yards, though above the mountains it is 800 yards, and at its mouth 500 yards. Vessels of burden can ascend no higher than the Mussel shoals, which extend 20 miles in length, and (except in high floods) interrupt the navigation. From these shoals it is navigable for vessels of 40 tons to the mouth of the Holstein, and up that river to Long Island, 600 miles from the mouth of the Tennessee.

Below the Ohio, the chief branches of the Mississippi are, the Arkansas, and the Red River, each of which add about 1000 miles of navigation. They rise in the mountains of New Mexico, and pass through the grazing country, which hitherto has been scarcely explored.

As the foregoing brief notice of the inland navigation of the Mississippi, and other waters of the United States, gives but a very partial view of the subject; the following is now subjoined.*

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[*] This is an exaggeration, common not only in Europe but in America also. It is not easy to fix the exact mean velocity of the current of any large stream: but from actual observation I am convinced that of the Mississippi falls far short of three miles per hour. DARBY.

The most south-western stream of the United States is that of the Sabine. This river has its source in the province of Texas, North Lat. 32° 30′. It flows in a general course nearly south, but curves to the eastward about mid-distance between its source and mouth. At North Lat. 30° it expands into a large lake, of 30 miles in length, and from 5 to 8 wide; which at its lower extremity again contracts into a river, and discharges into the gulf of Mexico, at North Lat. 29° 28′ West Long. from Washington city, 16° 45′.

The Sabine affords no navigation of consequence, having only 3 feet water on the bar at its mouth: the Sabine lake is also shallow, not having more than 4 or 5.

The Calcassiu is the next stream east of the Sabine. The former rises in the angle between the latter and Red river; flows nearly south about 120 miles, and falls into the gulf of Mexico, 30 miles east of the mouth of the Sabine. The Calcassiu, similar to the Sabine, expands into a lake, and again contracts into a river channel, before its final discharge. The former is also similar to the latter in its navigation, being impeded by a bar, and by the shallowness of its large lake. The mouth of the Calcassiu river is at North Lat. 29° 20′.

Following the coast of the gulf of Mexico, 12 miles east from the discharge of the Calcassiu, is found the entrance of the Mermentau. This latter stream is formed by a number of branches, having their sources in the prairies of Opelousas. The general course of the Mermentau is from north-east to south-west about 100 miles. It is remarkable as possessing similar features to the Calcassiu and Sabine rivers, and similar also in a defective navigation, arising from a bar at the entrance, and by the shallowness of its large lake, neither affording more than 3 or 4 feet water.

An interval of near 60 miles stretches east of the mouth of the Mermentau to that of the Vermilion, a fine but small stream, rising in Opelousas, but flowing through Attacapas into the gulf of Mexico, after an entire course of about 80 miles. The lands along the Vermillion river are of the first quality, producing cotton, and towards the mouth some plantations of sugar-cane have been successfully attempted; but vessels drawing more than 5 feet water cannot enter. The Vermillion enters the gulf of Mexico at North Lat. 29° 45′.

The united streams of Atchafalaya, Teche, and Courtableau, form a river of much greater importance and magnitude than any other in the United States, west of the Mississippi.

The Atchafalaya is the upper mouth of the Mississippi, and leaves the latter at North Lat. 31°, and West Long. from Washington city 14° 47′, by a stream 110 yards wide; its course is a little east of south, and by its windings 48 miles to where it receives the Courtableau from the north-west. Below the Courtableau, the Atchafalaya flows 80 miles, and is again augmented by the Teche, also from the north-west. After receiving the Teche the Atchafalaya flows 20 miles, where it is lost in a large bay, known by the same name. The Atchafalaya bay is about 23 miles long, and 13 miles wide. It is enclosed on the south west by two long narrow points of land, Point Chevreuil, and Point au Fer. Between those two points extends a bar, over which there is 9 feet water, and within the bay and river sufficient depth to permit the passage of any vessel to the mouth of the Teche, which can pass the bar. The mouth of Atchafalaya is at North Lat. 29° 21′; West Long. from Washington city, 14° 22′.

The Teche rises in Opelousas, and flowing 30 miles, enters Attacapas, where it receives a creek from the west, and assumes the form of a river. After entering Attacapas, the Teche continues, by a very winding course of 80 miles, a little east of south, to New Iberia, North Lat. 30° 2′. The town of New Iberia stands upon the right bank of the Teche, at the head of schooner or sloop navigation. Vessels, however, drawing five feet water, can ascend to this place at all seasons. The Teche, below New Iberia, gradually widens from about 20 to 100 yards, and deepens from 5 to 30 or 40 feet. Its stream now turns to E.S.E. and continues 90 miles, where it mingles its waters with the Atchafalaya.

The Teche is a small, but a very singular and important stream. In all its length it drains one of the most fertile tracts in the United States. On its upper waters cotton, and towards its mouth sugar and molasses, are the staples produced for market.

New Iberia is a port of entry, and vessels are frequently cleared out from that place, but the general commercial communication is with the city of New Orleans, through the Atchafalaya, Plaquemine, and Mississippi, or by the lakes Palourde and Verret, and the Lafourche and Mississippi rivers.

The Plaquemine is an outlet of the Mississippi, 117 miles above New Orleans. It is only during the seasons of flood that water is discharged into the Plaquemine, which, after a very circuitous course of 15 miles, joins the Atchafalaya. Through the Plaquemine is, however, transported most of the merchandise for the supply of the very flourishing settlements of Attacapas and Opelousas; and by this route is also sent to market the valuable staples of those places.

Boats from 15 or 20, to 50 or 60 tons, ascend from New Orleans, and entering the Plaquemine, pass into the Atchafalaya. Those destined to the lower part of Attacapas descend the latter river, and enter by the mouth of Teche. Those bound to the central part of Attacapas ascend the Atchafalaya about 20 miles, and thence, by an outlet and lake Chetimaches, proceed to the Fausse Point landing. Here is a portage of 10 or 12 miles to St. Martinsville, the chief town of Attacapas. Another outlet, and a chain of small lakes and bayous, (creeks) enable vessels to be conveyed to the upper part of Attacapas, and the lower part of Opelousas. Vessels destined for the higher and central parts of Opelousas, ascend the Atchafalaya to the mouth of Courtableau. and thence up the latter river to Lemell's landing, 6 miles, or into bayou Carron, within 4 miles from St. Landré, seat of justice and chief town of Opelousas.

The Courtableau is a fine little river, formed by the united streams of Crocodile and Bœuf. The two latter creeks unite at North Lat. 30° 40′. The general course of the Courtableau is S.E. about 30 miles in length. It affords, during high water, part of a very eligible channel of communication, between the settlements of Opelousas. and the lower part of Rapides, with the banks of the Mississippi.

The navigation of the Atchafalaya is entirely obstructed by rafts of timber, above the mouth of the Courtableau. These extraordinary masses of trees commence 26 miles below the efflux of the Atchafalaya from the Mississippi, and extend, by intervals, to within 5 miles of its junction with the Courtableau.

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* Darby.

Advancing along the gulf of Mexico, eastward from the mouth of Atchafalaya, the Lafourche is the first inlet of consequence, in a commercial point of view. In the intermediate distance of sixty miles, several small creeks enter the gulf, but from their very abridged length of course are unimportant.

The Lafourche, (the Fork) as its name imports, is an outlet of the Mississippi, and the second from the right in descending from the Atchafalaya, the Plaquemine being the first. The outlet of the Lafourche is at North Lat. 30° 6′; West Long. from Washington city, 14° 1′. After leaving the Mississippi, the general course of the Lafourche is south-east by south, 90 miles. It enters the gulf of Mexico at North Lat. 28° 57′; West Long. from Washington city, 13° 30′.

The Lafourche is one of the most important inlets of Louisiana, having 9 feet water on its bar, and admitting vessels drawing 4 or 5 feet to within 30 miles of its efflux. An arable border of extremely productive soil, skirts both banks of the Lafourche for 60 or 70 miles from the Mississippi. Cotton and sugar are the principal staples. Most of the produce and merchandise of the settlements along its banks, are transported by the route of the Mississippi, to and from New Orleans.

Between the mouth of the Lafourche and that of the Mississippi, several inlets admit a boat navigation to New Orleans. The principal of these bays is that of Barataria, by which, and a number of lakes and interlocking streams, a direct communication exists from the gulf of Mexico to the Mississippi at New Orleans.

The Mississippi itself has three main and three lesser passes or outlets. The most frequented of which is that of the south-east, upon the bar of which there is 12 feet water at low tides. Next to that of the south-east that of the south-west is the best entrance. The latter has indeed as great a depth of water as the former. Upon the south Pass there are 8 feet water. These three are the chief outlets of this great stream. The west, north, and Pass à la Loutre, have from 5 to 8 feet water on their respective bars.

Between New Orleans and Mobile bay, a very interesting inland navigation exists, through lake Pontchartrain, the Rigolets, lake Borgne, Pass au Christian, and Pass au Heron. This channel is formed by a chain of islands, the low marshy expanse north-east of the Mississippi river, and the main shore of Louisiana and Mississippi. Vessels above 5 feet draught cannot make this passage, as over either the shoals of the Pass au Christian, or Heron, that is the ordinary depth.

This interior channel is continued, to the north-west of New Orleans, by lake Pontchartrain, Pass au Manchac, lake Maurepas, Amite river, and bayou Iberville, to the Mississippi river, 125 miles, by water, above that city. Schooners drawing 5 feet water, go up as far as Galveztown, at the confluence of bayou Iberville and Amite rivers. From the efflux of the Iberville to the Pass of Heron is about 200 miles, 80 of which are to the north-west, and 120 to the north-east, by east, of New Orleans. Into this extensive channel are discharged, exclusive of the Amite and Mobile rivers; the Tickfoha, into lake Maurepas; the Tangipao and Chifuncte, into lake Pontchartrain; Pearl river into the Rigolets; and the Pascagoula, opposite Horn island. Each of those minor streams afford less or more facilities to navigation, but do not admit vessels of more than 5 feet draught but a very short distance from the sea. Schooners are most commonly used in the commerce of these inlets and shallow rivers. A steam-boat plies, however, between New Orleans, and Mobile and Blakely.

Mobile bay is a fine sheet of water, of 30 miles in length, with a medium width of 11 miles. Dauphin island, and Mobile Point, land-locks Mobile bay. The main entrance, with 18 feet of water, lies between the island and point. Pass au Heron, with 5 feet, lies between Dauphin island and the main shore of Alabama. A bar, with only 10 feet of water, crosses Mobile bay, about 5 miles below the town of Mobile.

Above Mobile town the bay gradually ceases, and is succeeded by a low sunken tract of 30 miles in length, and from 3 to 5 miles wide. Through this occasionally inundated tract, beside many minor streams, meanders the Mobile and Tensau rivers; the former being the continuation of the Tombigbee, and the latter of the Alabama river. Vessels drawing 5 feet water are taken as high in the Tombigbee as Fort St. Stephens, and in the Alabama to Fort Claiborne. At each of those two latter places, shoals impede the farther navigation of the rivers respectively, with vessels propelled by sails, though boats ascend and descend, in the Tombigbee, to Cotton Gin port, and in the Alabama, to its head at the junction of Coosa and Tallapoosa.

East of Mobile, Pensacola is the first harbour of any consequence. The Perdido intervenes, but having but little water, and terminating in a barren uninteresting country, merits no particular notice. Pensacola, to its depth of water, is one of the finest havens of the world. Its entrance is at North Lat. 30° 23′; West Long. from Washington city, 10° 20′. The entrance, between Rose island and Barancas point is over a bar having 22 feet water, upon a fine sandy bottom. The bay is about 20 miles in length, with a medium width of about 3 miles. The anchorage is, in every part, a soft mud or sand. No rocky banks or dangerous shoals environ this noble sheet of water. The bay, above the town of Pensacola, is divided into two arms; one, stretching north, receives the Escambia, and the other, to the north-east, the Yellow Water river.

The basin of the Appalachicola is remarkable, as forming the connecting link between the waters which flow into the gulf of Mexico from those which enter the Atlantic ocean. The Appalachicola is formed by two streams, the Chatahooche and Flint rivers. The former rises in the Appalachian mountains, at North Lat. 35°, interlocking with the sources of Tennessee, Oakmulgee, Oconee, and Savannah rivers; and flowing south-west by south, through two degrees of latitude, turns thence nearly due south, to North Lat. 30° 45′, where it receives the Flint. The latter, an inferior stream to the former, has its sources in the angle between the Oakmulgee and Chatahooche rivers, at North Lat. 33° 40′, and flowing south-west by south, 200 miles, unites with the Chatahooche, and forms the Appalachicola.

This latter fine river flows a little west of south, to North Lat. 29° 50′, having an entire course of about 70 miles; its mouth is into St. George's sound.

The basin of the Appalachicola affords an inland navigable expanse of 400 miles in length, with a mean width of 150, and having an area of about 20,000 square miles. Though interrupted by some falls, and many shoals, the rivers of Chatahooche and Flint are navigable almost to their sources; and schooners of considerable size ascend the Appalachicola to its head.

Cotton, tobacco, grain, tar, and lumber, are the common staples of this basin.

In all the immense distance, from Pensacola to the bay of Espiritu Santo, except the mouth of the Appalachicola, there is no inlet of any commercial consequence, in a general view.

The fine bay of Espiritu Santo is situated upon the west coast of the peninsula of East Florida, at North Lat. 27° 40′; West Long. from Washington city 6° 20′. There is about two feet more water upon the bar of Espiritu Santo than upon that of Pensacola, but the country around the latter remains so imperfectly known, that its commercial value cannot be estimated with any certainty at present.

Both these harbours are so land-locked, as to be safe from all winds, and are of great importance in situations where capacious or secure havens are rare.

The residue of the coast of Florida, from the bay of Espiritu Santo to St. Augustine, is so imperfectly known as to render any specific description impracticable, until more precise and detailed information is obtained.

St. Augustine is situated upon the eastern shore of the peninsula of Florida, at North Lat. 29° 42′; West Long. from Washington city 4° 30′. The harbour of this city is safe and commodious, but the bar at the entrance admits, at the highest tides, only vessels of 9 feet draught.

The mouth of St. John's river, at North Lat. 30° 20′, and nearly due north from St. Augustine, has still less water than the latter.

St. Mary's river opens a very deep and spacious entrance from the Atlantic ocean, at North Lat. 30° 43′, between Amelia and Cumberland islands. The St. Mary's river does not derive its source far inland, but the country it drains is in a great part fertile. Sugar and cotton are the most common and most valuable staples cultivated upon its banks; therefore, compared with its length of course, the St. Mary's river is amongst the most important streams upon the Atlantic coast of the United States.

The Altamaha is the first river of the United States, advancing from Cape Florida, which rises in the great spine of the Appalachian mountains. It is formed by two great branches, the Oakmulgee and Oconee, with many lesser tributaries. Both the Oconee and Oakmulgee have their sources in the mountains. Boats of 30 tons can be navigated upon the Altamaha, as far up as the town of Milledgville, 300 miles by the windings of the stream, and about as far in the Oakmulgee branch. This river discharges between St. Simonds and Sapelo islands, over a bar of 14 feet water at low tide.

Skirting the Atlantic Ocean, and extending from Cape Florida to the mouth of the Hudson river, extends a border of level sandy soil, through which the rivers wind in their courses from the interior. In most instances, the ocean tides penetrate this border to the base of the hilly or rocky region, but in no instance south-west of the Hudson does the tide pass the alluvial sea border. Such rivers, the sources of which originate in the Appalachian mountains, are uniformly precipitated over ledges of rock by rapids, in their passage from the hilly to the flat sandy sea region.

From this circumstance, all the great Atlantic rivers of that part of the United States, south-west of the Hudson, may be divided into three portions; first, the tide section, reaching from the ocean to the first ledges of rock crossing the streams; second, the short but strongly marked space occupied by the first rapids; and thirdly, and lastly, the residue of the stream above the head of the tides and the rapids already noticed.

These natural features produce an entire difference in the mode and manner of navigating the respective sections. Vessels propelled by sails or steam, are used almost exclusively as far as the tides extend. Above the tides and rapids, the navigation is performed with sharp keeled and flat-bottomed boats, which are impelled by oars, poles, or dragged by ropes, and the sail so little used as to scarcely deserve notice.

We will now proceed to review the residue of the Atlantic rivers of the United States, from the Savannah river to Passamaquoddy bay. After surveying their natural features, a view will then be taken of such artificial works, as have been executed, or projected, to facilitate navigation and commerce.

The basin of the Altamaha is followed by the small and unimportant basin of Ogeechee, about 150 miles in length, from north-west to south-east, with a mean width of 30 miles, comprising an area of 4500 square miles. The Edisto, and the Cambahee, augmented towards its mouth by the Camchee, from the west, rises in the small triangle between the Santee and Savannah rivers, nearly upon the line of separation between the primitive and sea sand alluvial formations.

The Savannah river basin follows rather that of the Altamaha, than that of Ogeehee. The Savannah river has its sources in the Appalachian mountains, on the primitive, over which it flows 150 miles, on its course towards the Atlantic ocean. At Augusta it leaves the primitive, and enters the alluvial sea sand, over which latter it again flows about 120 miles, having an entire comparative course of 270 miles. The sources of the Savannah interlock with those of Altamaha, Chatahooche, Tennessee, and Santee. It is a long stream, receiving but few tributary branches, and draining a basin 250 miles in length, by a mean width of 40 miles, comprising an area of 10,000 square miles. Large vessels ascend to Savannah, 18 miles from the Altantic ocean, and boats of considerable tonnage to Augusta. It is again navigable with boats to some distance above the falls or rapids at the latter place.

At the mouth of Savannah river the Atlantic coast turns in a nearly north-east direction 300 miles, to the entrance of Pamlicoe Sound. In this distance, leaving Savannah river, the first inlet is that round Port Royal island, into which the Coosahatchie river is discharged. Between the Coosahatchie and Charleston bar, the Cambahee and Edisto enter the Atlantic ocean. Neither of those three latter streams admit of extensive inland navigation.

Ashly and Cooper rivers are still more confined in extent than the Cambahee and Edisto, but the two former contribute to produce one of the finest harbours on the Atlantic coast of the United States, that of Charleston, in South Carolina. This noble haven is the mart of an extensive tract of country, chiefly watered by the tributary streams of the Santee.

The latter is a river of considerable magnitude, having its sources in the Appalachian mountains, at North Lat. 36°, West Lon. 5°, from Washington City, and falling into the Atlantic ocean at North Lat. 33° 12′, West Lon. 2° from Washington City: it consequently runs through three degrees of latitude and three degrees of longitude, having an entire length of 250 miles by comparative courses, and draining about 11 000 square miles. The Santee is formed by the united streams of the Wateree and Congaree rivers, both originating in the Appalachian mountains. The Wateree, in the higher part of its course, is known by the name of Catawba, and the Congaree is formed by the Saluda and Broad rivers. The Santee is navigable by sloops a considerable distance above the main fork, and steam-boats ascend at high water to Columbia, on the Congaree.

The Great Pedee follows the Santee in position and consequence. The Pedee rises at North Lat. 36° 30′, West Lon. from Washington City 4°, and flowing by comparative courses 250 miles, falls into Winyaw Bay, 12 miles below Georgetown, North Lat. 33° 18′, West Lon. from Washington City 2°. This river drains 15.000 square miles, and is navigable with boats of 40 or 50 tons burthen near 200 miles, following the winding of the stream. Near the mouth it receives Little Pedee, and Wackimau branches, both also navigable for some distance from their respective mouths. The Pedee, like the Altamaha, Savannah, and Santee, originates by both its great branches from the Appalachian mountains.

Cape Fear river rises in the hilly region intervening between the mountains and alluvial sea border, at about North Lat. 36°, West Lon. from Washington City 3°, and flowing south-east by south 200 miles, by comparative courses, falls into the Atlantic ocean at North Lat. 33° 50′, West Lon. from Washington City 1° 05′, and drains about 7000 square miles. Cape Fear river is formed by the stream of that name, properly so called, Black river, and the north-east Branch, all uniting above Wilmington. This river, having 18 feet water on its bar, affords the best navigation in North Carolina. Vessels drawing 11 feet water ascend to the city of Wilmington, 35 miles above the bar. Boats of sufficient tonnage for the commerce of the country, ascend in the main stream 105 miles to Fayetteville, and in the north-east Branch 70 miles above its confluence with Cape Fear river.

Between the mouth of Cape Fear river and Pamlico Sound, extends a range of low islands, with a narrow channel intervening between them and the main shore. Into this channel are discharged a number of small streams, undeserving particular notice.

Cape Lookout is remarkable as being the southern extremity of a very singular chain of long and narrow islands, enclosing two very large gulfs or sounds. Cape Lookout is at North Lat 34°, 22′, and East Lon. from Washington City 0° 05′, and is the south-west end of Corebank island. Between this island and the main shore extends Core Sound, about 20 miles in length, opening gradually into Pamlico Sound, between Ocricoke inlet and the mouth of Neuse river. From Cape Lookout to Cape Hatteras is 75 miles. At the latter the coast of the United States turns to nearly due north, which course it maintains 135 miles to the north of Chesapeake bay.

Cape Hatteras, at North Lat. 45° 10′, East Lon. from Washington City 1° 05′, forms the salient point of a long, low, sandy reef, extending from Ocricoke to New Inlet 60 miles. Within this reef spreads Pamlico Sound, into which are discharged Neuse and Pamlico rivers.

Neuse river rises in Orange county, in North Carolina, and flowing south east by east 160 miles, opens by a very wide estuary into Pamlico sound. The tides ascend Neuse 12 or 15 miles above Newbern, and thus far vessels of considerable tonnage are taken; the river is, however, navigable for boats to near its source. Neuse river rises at North Lat. 36°, West Lon. from Washington City 2° Its mouth is at North Lat. 34° 50′, East Lon. from Washington City, 0° 20′

North-east from Neuse flows the Pamlico river. The two streams originate nearly together, their general courses nearly parallel, and but very little difference exists in the space they respectively drain; taken together, they drain about 9000 square miles. Pamlico is frequently denominated Tar river; it rises near the southern border of Virginia, a little farther north than the sources of the Neuse river. Washington, Greenville, and Tarborough, towns of considerable trade, stand upon its banks. Vessels drawing 9 feet water ascend to the former place 40 miles; boats of 40 or 50 tons are navigated above Tarborough.

Thus far northward Cotton is more or less the staple commodity raised for exportation; but though that vegetable continues to be cultivated in the basin of the Roanoke and Chowan, it is more rare and of less value than more southwardly.

North-east from the mouth of the Pamlico river stretches a flat marshy Peninsula, 60 miles in length by 45 in breadth. This peninsula is limited on the east by the narrow inlet which unites Pamlico and Albemarle sounds, and is united to the main land by a comparatively wide isthmus, between Washington on the Pamlico, and the mouth of Roanoke river. The counties of Washington, Hyde, Tyrrel, and Beaufort, in North Carolina, occcupy the extensive alluvial tract between Pamlico and Albemarle sounds.

The latter is the estuary of two large rivers, the Roanoke and Chowan. The Roanoke rises in the chain of the Appalachian mountains, and is formed by two branches, the Staunton and Dan rivers. Thus far, the eastern side of the Blue ridge bounds the sources of the Atlantic streams, but the Staunton branch of Roanoke rises west of the Blue ridge, in Bottetourt and Montgomery counties in Virginia, interlocking with the sources of the Great Kenhawa branch of Ohio, and James river flowing into Chesapeake bay. After forming a considerable stream it pierces the Blue Ridge, and winding about 150 miles by comparative courses, joins Dan river between Halifax and Charlotte counties in Virginia. The extreme northern source of the Staunton river is at North Lat. 37° 25′, West Lon. from Washington City 3° 20′. Dan river rises partly in Virginia and partly in North Carolina, by a great number of small branches, flowing from the Blue ridge, and opposite to the sources of the Great Kenhawa. Below the junction of the Dan and Staunton, the united streams taking the name of the Roanoke, flows by comparative courses south-east by east 150 miles, falls into the south-west angle of Albemarle sound. The tide flows up the Roanoke to Halifax, at the foot of the Great Falls, about 100 miles following the windings of the river, and 75 miles by land from the mouth.

Vessels of 40 or 45 tons ascend to the falls, and above those natural obstructions the river is navigable for large batteaux to the junction of the Dan and Staunton rivers, and by others of lesser draught to the mountains.

The Chowan is formed by the waters of the Meherin, Nottaway, and Blackwater. The Nottaway rises at North Lat. 37° 15′, West Lon. from Washington City 1° 40′. Its general course is south-east 115 miles by comparative course. The junction of the Roanoke and

Chowan is at North Lat. 36°, and due south from Washington City. The latter is navigable for vessels of considerable tonnage as far as the main forks, and for smaller vessels some distance up each branch.

The Roanoke and Chowan yield a very extensive and lucrative commerce. The lands upon the latter are considered amongst the most productive of any of the Atlantic streams. Tobacco is the principal staple commodity of this fine basin. The Albemarle sound communicates with the Atlantic ocean by two inlets, the Roanoke and Currituck.

From the general course of the Blackwater branch, and of the Chowan below their junction, an extensive flat peninsula is formed between Albemarle sound, Chesapeake bay, and James river, of about 70 miles in length from north to south, by 50 mean width, east and west, or 3500 square miles. This extensive flat region is occupied by Currituck, Camden, Pasquotank, Perquimans, Chowan, and Gates's counties in North Carolina, and by the Isle of Wight, Nansemond, Norfolk and Princess Anne counties in Virginia. Though the central parts are occupied by the Dismal swamp, and much of the residue marshy, yet, by the census of 1820, the ten counties comprise a population of 87,510 inhabitants. The canal already executed between the Albemarle sound and Nansemond river will be noticed in the sequel of this article.

Under the general head of the confluents of Chesapeake bay is included a basin of navigation, in form of an immense triangle, having 450 miles base from the extreme southern sources of Nansemond river, North Lat. 36° 40′ to those of the Chenango branch of Susquehanna, North Lat. 42° 55′; and 250 miles perpendicular from Cape Henry, North Lat. 37°, East Lon. from Washington City 1° 10′, to the extreme western sources of James river, North Lat. 37° 15′, West Lon. from Washington City 3° 30′, with an area of 65,000 square miles. This is by far the most extensive and peculiar basin of the Atlantic slope of the United States. The bay of Chesapeake penetrates it from north to south 175 miles. Into the western side of this great bay, or rather gulf, flow a number of tributary branches, of which the principal are, James river, York river, Rappahannoc, Potomac, Patuxent, Patapsco, and Susquehanna:—of these in their order from south to north.

James river, the great southern tributary of the Chesapeake basin, rises by a number of sources in the valley of the Appalachian chain, interlocking with the sources of the Great Kenhawa. The approximation of those two rivers forms the channel by which the legislature of Virginia contemplates a junction between the Atlantic and Ohio waters. The intended improvements in order to effect this object will be amply noticed in the sequel of these articles.

The mountain sources of James river having united in Rockbridge county in Virginia, where they have already formed a considerable river, it pierces the Blue ridge, and enters the hilly region between the mountains and Atlantic alluvion, and resuming a course of south-east by east 220 miles by comparative courses, falls into Chesapeake bay between Point Comfort and Willoughby Point. After its egress from the Blue ridge, James river receives a number of tributary streams, the principal of which are, Rivanna and Chickahomna from the left, and Appomattox from the right. The tide flows up James river to Richmond, and in the Appomatox to Petersburg. Vessels of upwards of 100 tons burthen ascend to either of those cities.

That remarkable range of gneiss rock, which impedes the navigation of all the rivers which flow over it, from the Appomattox to the Delaware inclusive, becomes, advancing from the south, first in a remarkable manner conspicuous at Petersburg, and, as will be seen, terminates, or sinks beneath the incumbent earth at Trenton. This primitive barrier has a very great influence over the inland navigation of a very interesting section of the United States. It will be more particularly noticed when treating upon canals

York river follows James river. The latter rises in the north-east mountains, and drains the angle between James and Rappahannoc rivers, and flowing nearly parallel to the former by a comparative course of about 200 miles, falls into Chesapeake bay 16 miles north-west by north from the mouth of James river. York river is formed by the Pamunkey and Mattapony rivers, which unite 35 miles from the Chesapeake bay; the tide ascends some distance up each branch, and, as far as their junction, ships of 1000 tons may be navigated with ease and safety.

Rappahannoc river rises on the south-eastern slope of the Blue ridge, interlocking with the Rivanna branch of James river and the Shenandoah branch of Potomac; it is formed by the Rappahannoc, properly so called, and Rapid Ann rivers, which unite about 10 miles above Fredericksburg, after a course respectively of 60 miles. The tides are arrested at Fredericksburg by the gneiss ledge already noticed. Thus far vessels of 140 tons are navigated.

The Potomac next demands our attention. This is a stream of incalculable importance in the interior or inland navigation of the United States. If we turn our eye to a map of Virginia, we perceive the extreme north-western sources of James river flowing to the south-west along the mountain valleys, and extending our view to the head waters of Potomac, we behold them flowing parallel to each other north-east, also down the mountain valleys; and in the latter case we are struck with the very remarkable fact, that the Potomac rises west of all the ridges of the Appalachian system, except that denominated Laurel Hill. The south-west angle of Maryland, or extreme western source of the Potomac, having the residue of the collateral ridges to pierce in its progres towards its recipient, the Chesapeake bay. This peculiar structure of the river valleys of the United States yields an unequalled facility of forming inland water communications through a very broad chain of mountains. Before proceeding to describe the Potomac or Susquehanna, it may be remarked, that the Appalachian, or Allegheny system of mountains, does not form the dividing ridge which separates the waters flowing into the Atlantic ocean from those which enter the Mississippi basin; but that the separating river line cuts the mountains obliquely. But to return to our survey.

The Potomac, draining the valleys of the Appalachian mountains from North Lat. 38° 25′. to 40°, unites its various branches before piercing the Blue Ridge, which it finally effects at Harper's Ferry, 60 miles north-west from Washington city. Below its passage through the Blue Ridge to its egress into Chesapeake bay is about 200 miles, following the windings of the stream. The tide ascends to Georgetown, 3 miles above the capital in Washington, where it is arrested by the gneiss range of rocks. Ships of the largest class are navigated to the Navy yard, one mile below the capitol. Like all other tributaries of Chesapeake bay, the Potomac, below the head of tide water, opens gradually into a long narrow bay. By a singular caprice of custom, the Susquehanna is considered as terminating at the head of tide water, whilst in nature, what is known by the name of Chesapeake bay is merely the continuation of that noble river; and in strictness, James river, York river, Rappahannoc river, and Potomac, are tributaries to the Susquehanna.

The sources of Cheat river branch of the Monongahela rise in Randolph county in Virginia, in the same valley with the Potomac, and those of the Youghiogany, with a single intervening ridge, separating them from those of Potomac, partly in Randolph and Monongahela counties in Virginia, and partly in Allegany county in Maryland. Thus, here again occurs the second instance of advancing from the south to north of the origin of waters, flowing into the two opposite systems of the Mexican Gulf and Atlantic Ocean, without an intervening mountain, and yet amidst the Appalachian ridges. The peculiar features we have noticed in this section of country has drawn the attention of persons inquiring into the subject of canal connexion between the two river systems. The facilities afforded to such designs by the connecting waters of the Potomac and Monongahela will be more particularly noticed in its proper place.

The south-east and main source of the Potomac rises in Pendleton county in Virginia, at North Lat. 38° 25′, and the next considerable stream of the valley, the Shenandoah, rises in Augusta county, as far south as North Lat. 38°. The latter overheads the sources of York and Rappahannoc rivers, and interlocks with the sources of James river: the middle ridge of the Appalachian, or the mountain properly called the Kittatinny, ranges between the Potomac proper, and the Shenandoah. Both rivers and all their branches flow to the north-east down the mountain vallies. The Potomac continues in that direction as far as North Lat. 39° 41′, within two miles of the south boundary of Pennsylvania, whence it turns at right angles, pierces the Kittatinny mountain, and flows to the south-east. Forty miles by comparative courses, below its passage through the Kittatinny, the Potomac receives the Shenandoah from the south-west, and the united waters here pierce the Blue Ridge. This latter passage of the Potomac through another of the Appalachian ridges is known as the celebrated Harper's Ferry. At their junction, the Potomac has flowed by comparative courses 160, and the Shenandoah 120 miles.

From Harper's Ferry to the head of tide water, or to where the Potomac quits the primitive and enters the alluvial sea border formation, is 50 miles, and thence continuing by a general course south-east, and by comparative courses 100 miles, that river is lost in the Chesapeake bay at North Lat. 38°, having regained exactly the latitude of the sources of Shenandoah. The entire length of the Potomac valley, as it is, is 300 miles, presenting a very remarkable navigable channel. Many of its minor valleys are composed of very productive soil, and already an immense amount of produce is reared within, and transported to the Atlantic ports from, this valley.

It may be remarked that tobacco, as a staple commodity in large quantities, may be considered as limited by this valley, whilst wheat, rye, and the apple, as staples, may be viewed as commencing. From the peculiar form of the valley, and from the very great difference of elevation of its parts, it presents a greater variety of climate than could be, at a first glance upon its extent and position on a map, believed probable. If climate and the features of nature are both taken into the account, the Potomac presents the most favorable facilities of any river in the Susquehanna basin to effect a water communication between the Atlantic ocean and the valley of Ohio.

The Potomac, in its natural state, is the most navigable branch of the Susquehanna. Ships of any burthen can be brought up to the Navy yard at Washington, five miles below the extreme head of tide water. Washington is upwards of 100 miles in a direct line; and following the Chesapeake bay and Potomac river, about 200 miles distant from the Atlantic ocean. Washington is therefore the point in the United States, to which the largest vessels can be navigated the farthest into the interior of the continent.

This subject will be more particularly noticed, when we come to examine the subject of canals.

The next stream flowing into Chesapeake bay, after the Potomac, is the Patuxent, affording however too few navigable facilities to merit particular notice. Patapsco bay and river follows the Patuxent. At the head of Patapsco bay, 12 miles above Chesapeake bay, and at the foot of the primitive ledge, stands the city of Baltimore. To the lower part of this city or Fell's Point, vessels of 500 and 600 tons ascend. Between the mouth of the Potomac and that of Susquehanna are several indentings of the right shore of Chesapeake bay besides Patuxent and Patapsco, but, except the two latter, the others are of too little moment to be correctly included in a general view. The Maryland part of the eastern or left shore of Chesapeake is also much broken by small rivers and bays; the principal of which are the Pocomoke river from Worcester county; Manekin and Wicomico from Somerset county; Nanticoke river in the state of Delaware, flowing into Maryland, dividing Dorchester and Somerset counties; Choptank, the longest river of the peninsula between the Atlantic ocean and Chesapeake bay, rising also in Delaware, and entering Maryland in Caroline county, enters Chesapeake, separating Talbot and Dorchester counties; St. Michael's bay, separating Talbot and Queen Ann counties; Chester river, separating Kent and Queen Ann; Sassafras, separating Kent and Cœcil counties, and, finally, Elk river in Cœcil county. These latter bays, rivers, and creeks, have more or less water, and admit vessels suitable to the commerce of the country they drain. The three latter, Chester, Sassafras, and Elk rivers, are the channels through which projected canals, and other improvements, have at different times designed to unite the Chesapeake and Delaware bays.

The Susquehanna loses its name at the foot of its falls, at North Lat. 39° 33′, exactly one degree East from Washington. From its magnitude, and from the western origin of its sources, the Susquehanna seems to form a natural chain of water communication between the Atlantic ocean and Ohio valley; and the curious fact, that all its great tributaries flow from the right and completely pierce the Appalachian chain, renders this observation still more striking. If we turn our attention to the general physiognomy of the Susquehanna, we find its extreme northern source in Madison county, New-York, within 16 miles of Oneida lake, and 15 from the line of the Great Canal, and in the angle between the sources of the Mohawk and Seneca rivers. This is the Chenango river, afterwards augmented by the East branch. The latter originates in the northern spine of the Catsbergs, in the angle between the heads of the Coquago branch of Delaware, the Chenango, and opposite to the Mohawk river, reaching within less than ten miles from the line of the Great Canal of New-York. The East branch is correctly so called, as its sources are in fact the most eastern tributary waters of the Susquehanna. The East branch and Chenango unite in Broome county in New-York; the former having by an abrubt curve entered and retreated from Pennsylvania. Below their junction the united waters flow a little south of west, enter Tioga county in New-York, and turning nearly south into Bradford county in Pennsylvania, receive the Tioga branch from the north-west, at Tioga Point.

The Tioga river rises in the angle between the sources of the Genesee and Seneca rivers, in Steuben, Allegheny, and Ontario counties, in New York, and within 30 miles from the line of the Great Canal.

The general course of the Tioga river is from north-west to south-east, by comparative courses about 80 miles. The general course of the Susquehanna proper, already noticed, is from north-east to south-west, by comparative courses 120 miles.

What in a particular manner renders remarkable the two great northern constituents of the Susquehanna, is their enclosing the two long and navigable lakes Seneca and Cayuga; the latter stretching, in an almost direct line, from the Great Canal to within 20 miles of the Tioga river, at the mouth of the Newtown creek, about 20 miles, by comparative courses, above Tioga Point; and the latter, or Cayuga, stretching also from the line of the Great Canal, to within 30 miles from the Susquehanna, at the mouth of the Oswego, about 20 miles above Tioga Point. Nature, in this section of country, seems to have advanced half way to aid the efforts of man in forming channels of communication between the basins of the Susquehanna and St. Lawrence. The two fine lakes of Seneca and Cayuga are each respectively upwards of 35 miles in length, and occupying the angle between the two main northern constituents of the Susquehanna, would appear to have been placed in their actual position, as if to give, in their utmost extent, the greatest navigable facility.

From the Tioga Point, the Susquehanna flows by comparative courses 60 miles, to the mouth of the Lawahannoc creek, in the centre of Luzerne county. In this range, the river flows nearly due south, 10 miles to the western, or, more correctly, north-western, verge of the Appalachian mountains. Hitherto, the entire tributary waters of this stream have originated and flown north-west of the Appalachian chain, and on the secondary formation. At the mouths of the Towanda and Wysaukin creeks, the river curves to S. E. and enters the mountains, nearly at right angles to their general range. Continuing about 10 miles still farther upon the secondary, the river enters on the great central transition formation, near the mouth of the Tunkhannoc, where it passes the main ridge of the Appalachian chain, and issues into the fine valley of Wyoming, across which it maintains a south-east course to the mouth of the Lawahannoc. Here the now noble stream of the Susquehanna again turns at nearly right angles, and flows down the remarkable Wyoming valley, by comparative courses, 70 miles, to its junction with the west branch at Northumberland and Sunbury.

The west branch rises entirely in Pennsylvania, and within the Appalachian valleys, though upon the secondary formation. Its general course is nearly from west to east, by comparative courses, 150 miles, to where it passes the main ridge of the Appalachian chain, and enters on the transition formation 20 miles below Williamsport. Here the river pierces the mountain, flows into the great valley, and turning to nearly due south 25 miles, to its junction with the Susquehanna.

Below the mouth of the West Branch, the Susquehanna pursues a general direction, a little west of south, 40 miles to the mouth of the Juniata. The latter is literally a mountain stream, and has its whole valley on the central transition formation. Its general course is nearly from west to east, parallel to the West Branch. Similar to the other secondary rivers of the basin of the Susquehanna, the Juniata traverses the Appalachian ridges in several places, and flows in either a parallel direction, or at right angles to those ridges.

Below the mouth of Juniata, the Susquehanna assumes a south-east direction of 80 miles, by comparative courses, and being precipitated from the primitive on the sea-sand formation, loses its name and rank as a river in Chesapeake Bay.

Between the head of the latter bay, and the mouth of the Juniata, the Susquehanna passes three mountain ridges: the Kittatinny above, and the Blue Ridge below Harrisburgh, and what may correctly be called the south-east mountain, below the mouth of the Conestogo and Pequea creeks.

The valley of the Susquehanna proper presents an area of inland navigation of about 20,000 square miles.

If we turn our eye to the whole basin of the Susquehanna, and consider it geographically, we have before us a mighty link, which connects the three great river systems of North America—those of the Gulf of Mexico, St. Lawrence, and Atlantic Ocean proper. The natural facilities it presents to channels of inland navigation will be shown in the sequel, with the relative elevation of its mountain valleys, and the obstructions opposed to artificial water routes.

If we examine this basin geologically, we find its general physiognomy, in a very remarkable manner, commanding our attention. We have in this basin all the formations which the world affords, from the highest class of primitive rocks, to the most recent alluvion. And we have all those formations on an immense scale. But the circumstance arising out of this geological structure, most worthy of our attentive observation, is, that the courses of the waters, or their fitness, or unfitness for navigation, appears to be totally independent of the rock formations. It appears, also, that, although the mere windings of the streams are influenced by the mountain ridges, that their general courses towards the recipient, into which the waters are discharged, have no dependence upon either the mountains or rock formation. The latter character the Susquehanna basin partakes, in common with its three contiguous Atlantic basins, those of Roanoke, Delaware, and Hudson.

These very important facts prove how little we are advanced in a correct view of any of these basins, in a navigable point of view, by the most minute knowledge of the relative position of the mountains, the extent and relative position of the different formations, or, more, that of the courses of the rivers themselves. Falls, in the proper sense of the term, are rare in any of the Atlantic rivers. What are usually denominated falls are in reality rapids; but those, in respect to either their position or magnitude, have but an incidental connexion with the mountain ridges. In most instances, where the rivers do pass the mountains, rapids occur; but this coincidence is by no means universal. The rivers, in a number of the mountain gaps, present an intervening smooth sheet of water. This is remarkably the case with the Juniata, below Bedford, and with the Lehigh, at its passage through the Kittatinny range. The real fall of the water, in its descent from the mountain valleys to the level of the tides, can in no instance be even tolerably correctly estimated by a comparison with its course through the mountains. Every stream, to be well understood, must be surveyed separately, and considered a whole in itself.

Before quitting the general review of the basin of the Susquehanna, we may remark, that the main volume of that river, from its source to the Atlantic, receives all its large tributary streams from the right, and serves as a common recipient, lying along the base of an inclined plain, extending from the 37th to the 42d degree of north latitude. It will be seen by inspection, that this feature is also prominent in the physiognomy of the Potomac, Delaware, and the Hudson.

The Delaware basin, intervening between that of Susquehanna and that of the Hudson, extends about 250 miles from north to south, with a mean width of 60 miles, extending over an area of 15,600 square miles. The Delaware rises by two branches in the Catsbergs, draining the angle between the Susquehanna and Schoharie branch of Mohawk. The sources of the Delaware flow south-west, by comparative courses, 50 miles, through Delaware county, in New York, unite at the north-east angle of Pennsylvania, and turn at right angles to a course of south-east; following the latter direction, by comparative courses, 70 miles, to the north-west angle of New Jersey, and the base of the Kittatinny mountain; again turning with the mountain to the south-west, follows that course along its base, by comparative courses, 40 miles, to the mouth of Broadhead creek, where the river again turns, and passes the Kittatinny mountain. The general physiognomy of the Susquehanna and Delaware, every where remarkable, is in no other place so striking as in the valley between the Kittatinny mountain and the continuation of the Blue Ridge, below Easton and the mouth of the Lehigh. I have already noticed that reach of the Susquehanna from the mouth of the West Branch to that of the Juniata. A corresponding reach in the Delaware extends across the Kittatinny valley, to where the river pierces the south-east mountain.

In the Kittatinny valley, 25 miles, by comparative courses, below the Delaware water gap, the Lehigh comes in from the north-west.

The latter stream claims a very large share of attention, as being one of the great channels from which the city of Philadelphia, and indeed the whole Atlantic coast, is destined to receive exhaustless supplies of coal. Our notice of the Lehigh need be only brief in this general view, as an ample survey of its valley, as a navigable route, will be made, when we reach the subject of canals.

This branch of the Delaware rises in Wayne, Luzerne, and Northampton, and is, emphatically, a mountain stream. Flowing first to south-west, curves to south and south-east, pierces the Kittatinny mountain, crosses the Kittatinny valley in a south-east direction, is turned by the south-east mountain at Allentown, where it winds to north-east, and joins the Delaware at the borough of Easton, after a comparative course of about 80 miles.

Below the south-east mountain, the Delaware turns to a south-east course 35 miles, to where it leaves the primitive, and falls into the alluvial formation at the head of tide-water. Continuing over the alluvion four or five miles, the Delaware again turns to south-west, nearly parallel to, and about five miles distant from, the primitive ledge, in which direction it flows, by comparative courses, 35 miles, to the mouth of the Schuylkill.

As with the Lehigh, we may reserve to the subject of canals, most of what we have to say respecting the Schuylkill: it is sufficent to observe, that the latter has its principal sources in Northampton and Schuylkill counties; that its general course is from north-west to south-east, by comparative courses, 120 miles. Few secondary rivers of the American continent are destined to become of equal importance with the Schuylkill, as a channel of inland navigation. The general course of south-west is maintained by the Delaware, about 30 miles below the mouth of the Schuylkill, or about 5 miles below New Castle. Here the river, already considerably expanded in width, opens into a wide triangular bay, 60 miles in length, and 20 wide, between Capes Henlopen and May.

The basin of Delaware reaches through three and one-third degrees of latitude, and extends almost directly from north to south.

Leaving that of the Delaware, the basin of the Hudson next presents itself. If we include Rariton bay and river, the bay of Newark, with its two small confluent rivers, Hackinsack and Possaick, and the contiguous part of Long-Island sound, in the Hudson basin, we have before us a very curious connexion between inland and maritime navigation. Taken with this extension, the Hudson basin reaches from Sandy Hook North Lat. 40° 30′, to the extreme sources of the Hudson in North Lat. 44° 05′, or about 250 miles in length, with a mean width of 50 miles, exclusive of the western part of the valley of the Mohawk above the mouth of the Schoharie river. This latter section includes a parallelogram of 60 miles long, and 35 wide. The whole basin spreading over an area of 14,600 square miles.

It will be observed that the rivers in the Atlantic system, south-west of the basin of the Susquehanna, flow, with the exception of the St. John's river of Florida, from the north-west and south-east. The Susquehanna, on the contrary, flows from north to south, and all the other Atlantic rivers to the north-east of the basin of the Susquehanna to the Penobscot inclusive, flow also in a similar direction nearly.

At the mouth of the Hudson, the primitive rock reaches the shore of the Atlantic Ocean, the tides of which in the first and last place, along the coast of the United States, passes that barrier, and traversing the base of two ranges of mountains, penetrates the continent nearly as far as the confluence of the Hudson and Mohawk rivers, one hundred and sixty-five miles. What is most extraordinary in this long, narrow, but deep bay, rifted by the hand of nature through primitive mountains, is, that through one ridge, a depth of water is found sufficient for ships of the line of the largest class. Newburgh, placed nearly on the line of separation between the primitive and transition formations, and actually in one of the Appalachian valleys, has been proposed as the site of a navy-yard, in which the heaviest vessels could be launched, and from thence conducted to the ocean. Newburgh is situated 70 miles inland, and, as we have seen, on the interior verge of the primitive. Above this place, the bay or river gradually shoals, but sufficient depth continues to the head of tide-water for sloops of considerable burthen. Albany 160, and Troy 165 miles above Sandy Hook, may be considered as the two most remote points from the Atlantic Ocean, in the United States, by a direct line to which the tides flow, and to which sea vessels can be navigated.

All the small water courses, which flow into the Hudson, below its confluence with the Mohawk, are precipitated from a very great comparative height, and reach their common recipient by a series of cataracts. These small streams are generally abundant in the driest seasons, and afford, it is probable, the most extended connected lines of manufacturing sites on the globe; sites placed upon the very brink of one of those extraordinary channels of inland commerce, which cannot be seen without astonishment.

The protrusion of the Canadian lakes towards the Atlantic rivers, which we have noticed as remarkable, north of the Susquehanna basin, occurs again in a still more striking manner, with the Hudson and Lake Champlain. The head of the latter approaches tide water in the former, to within 60 miles, with a difference of level of 86.5 feet, and the highest elevation of the intervening valley 142 feet. From the Hudson river, however, below Baker's Falls, to Whitehall on lake Champlain, is about twenty-three miles. This is the route of the northern canal of New York, which will be more particularly noticed in the sequel. A similar reservation may be made respecting the residue of the basin; as, in the notice of the Grand Canal, every necessary observation will be included.

Long Island Sound, east of the mouth of the Hudson, receives, besides the Connecticut river, the Housatonick, and Quinnipiack, between the Hudson and Connecticut; and the Thames east of the latter. From their elevated origin, and abridged courses, those minor streams contribute but little to the inland commerce of the sections of country they drain, though New Haven at the mouth of Quinnipiack, New London near the mouth, and Norwich near the fork of the Thames, are flourishing commercial towns.

Connecticut is amongst the most curious of the Atlantic rivers. Its extreme northern sources are in a hilly though not mountainous country, at North Lat. 45° 10′, interlocking with the sources of the St. Francis, branch of St. Lawrence, and with those of the Kennebec, assuming a course of a little west of south, down a valley between two ranges of mountains, separating Vermont from New-Hampshire, to North Lat. 42° 43′. Thence crossing Massachusetts and Connecticut in a direction of nearly due south, finally at Middletown turns to north-east, and enters Long Island Sound at North Lat. 41° 16′. The entire length of the Connecticut basin is 280 miles, with a mean width of about 45 miles, draining 12,600 square miles.

Though the basin of Connecticut is almost entirely on the primitive rock, and though passing one small ridge of mountains near Middletown, it is nevertheless navigable for vessels drawing ten feet water to the latter place, above the mountain pass 36 miles by the windings of the stream from the mouth; and by vessels of 7½ feet draught to Hartford, 15 miles still higher than Middletown. The latter place is at the head of ship navigation, but, though considerably obstructed by falls, rapids, and shoals, the navigation of this river has been so much improved by dams, locks, and short canals, as to permit boats of considerable tonnage to ascend to, and descend from, the fifteen mile falls above Haverhill, upwards of 250 miles, following the stream from Long Island Sound. This is very considerably the deepest inland navigation in the United States, east of the Hudson.

The Connecticut flows down nearly along the middle of its basin, and in all its length comparatively of 280, and by its meanders of near 400 miles, does not receive one considerable tributary branch.

Narragansett and Buzzard's bay are two deep indentings of the Atlantic coast, between Long Island Sound and that singular peninsula called Cape Cod. The latter, extending nearly in a north and south direction 30 miles, receives from the north-west the Pawtucket, and from the north-east the Taunton river. The city of Providence, the third in size in the United States, beyond New York to the north-eastward, stands at the head of Narragansett bay, near the mouth of Taunton river. To its extent the basin of Narragansett presents the most extensive inland commerce in the United States. The bay of Narragansett is, at once, one of the most picturesque and interesting sheets of water on the Atlantic coast. It is filled with islands rising considerably above the level of the highest tides. Sufficient depth of water is found at the entrance for ships of the heaviest tonnage, and to Providence for merchant vessels of the largest class.

Buzzard's bay, extending to the north-east between the main shore of Massachusetts and Elizabeth islands and Barnstable peninsula, is more extensive, but much less navigable than that of Narragansett. The extreme head of Buzzard's bay reaches within 7 miles of Sandwich harbour, in Cape Cod bay. Here is one of the points where a canal has long been projected to unite the two bays, and to facilitate the coasting, or, correctly speaking, inland navigation of the United States. The depth of water, and smallness of the tides in Buzzard's bay, seems, however, to preclude any very beneficial improvement as a channel of commercial intercourse.

Cape Cod, stretching near 40 miles directly into the Atlantic ocean, and then protruding an arm of almost equal length, encloses a wide circular bay. This bay may, nevertheless, be viewed as extending to Cape Ann, 45° N. N. W. from Cape Cod. With such extension, this bay would reach from Barnstable to Salem, 65 miles, with a mean width of 20 miles. This large bay contains, besides many of smaller note, the harbours of Plymouth, Boston, and Salem, though receiving no water course, the sources of which are 20 miles inland. The small streams flowing into Narragansett bay, and into the Concord branch of Merrimac river, interlock within less than twenty miles south-west from Boston.

The Merrimac, rising in the White mountains of New Hampshire at North Lat. 44° 10′, flows south south-east, by comparative courses, about 100 miles, turns abruptly to north-east by north 25 miles, falls into the Atlantic Ocean 20 miles due north from Salem. The Merrimac basin is about 130 miles in length by a mean width of 36 miles, embracing an area of 4550 square miles. The navigation of this river has been more improven by art than any other stream of the United States. Those improvements will be noticed under the head of canals.

The flourishing town of Newburyport stands at the mouth of the Merrimac, and vessels of 100 tons ascend to Haverhill, 12 miles above the former place. The tides are arrested near Haverhill by the rapid ascent of the interior country; all navigation beyond, to Concord, has been effected by human labour.

From some cause hitherto not very satisfactorily explained, Cape Cod forms a remarkable point of separation between the Atlantic tides. To the south-west of that peninsula the tides become more and more moderate, but here at once an excessive change takes place. In Buzzard's bay the tides do not exceed 4½ feet, whilst in that of Cape Cod they amount to 17 or 18 feet perpendicular, and increase, advancing to the north-east, until in the bay of Fundy the ocean swells pour on the coast with the enormous weight of upwards of 60 feet. This peculiar circumstance renders the rivers more navigable, upon an equal descent, to the north-east, than to the south-west of Cape Cod, though the rapid acclivity of the former section of country compensates in a great measure for the natural advantage of such excessive tides. Another advantage is, however, gained by the high swell, and depression of the north-eastern tides, that is, to render the rivers much less liable to be frozen over in winter.

The small basin of Piscataqua, enclosed between those of Merrimac and Saco, gains celebrity from possessing the fine haven of Portsmouth in New Hampshire. It is otherwise unimportant, and becomes unnavigable at a short distance from the head of Great Bay. From the extreme rapidity of the ebb and flow of the tides, the water in Portsmouth harbour is never so much frozen as to obstruct navigation to any great extent. The basin of the Piscataqua embraces an area of about 800 square miles.

The Saco heads in the White mountains, interlocking with the sources of the Merrimac, Connecticut, and the Androscoggin branch of the Kennebec. This river is only navigable by sea vessels 7 miles, to the head of tide water at Biddeford. Its basin is about 65 miles in length, by a mean width of 25 miles, comprising an area of upwards of 1600 square miles.

The basin of Presumscot or Casco follows that of Saco. The former, though inferior in extent, is nevertheless, in a navigable point of view, of superior consequence to the latter. The Presumscot river has its sources between those of Saco and the Androscoggin, and after a comparative course of 50 miles falls into Casco Bay at Falmouth, opposite to Portland in Maine. The basin of the Presumscot is about 50 miles long from north-west to south-east, with a mean width of 10 miles, comprising an area of about 500 square miles. Here again the tides are arrested by the approaching high country, and reach but a small distance into the Presumscot.

Casco bay is a fine sheet of water, 20 miles long by 5 miles wide, filled with numerous islands, and having sufficient depth of water to Portland for ships of the first rate.

At Casco the character and direction of the coast of the United States again changes. From the mouth of the Chesapeake bay to that of the Hudson, 250 miles, the Atlantic coast extends a little east of north. From Sandy Hook to Buzzard's bay, 200 miles, the coast turns to north-east by east. Including Cape Cod, the bearing of the coast from Buzzard's Bay to Casco Bay, is nearly from south to north 150 miles.

In all this great range of coast, of 600 miles, though much indented by bays and rivers, and chequered with islands, yet comparatively it is compact and uniform, when contrasted with that extending 200 miles, between Casco and Passamaquoddy inclusive. Here the coast stretches something east of north-east, and is more broken than any other equal distance of the coast of America, upon either the Atlantic or Pacific Oceans.

In a survey relating rather to the river basins than to their egress into their common recipient, it would be irrelevant to even name the many deep inlets between Casco and Passamaquoddy bays; we will therefore pursue our review of the rivers.

Casco bay is succeeded to the north-east by the intricate outlet of the Kennebec. The latter river is formed by the union of the Kennebec proper with the Androscoggin, and drains a basin of 150 miles in length, with a mean width of 80 miles, embracing an area of about 12,000 square miles. The tide flows up the Kennebec to Augusta 45 miles, and in the Androscoggin to near Durham. Though interrupted by falls and shoals, both branches afford very considerable extent of inland navigation. Teconich falls occur in the Kennebec at Waterville, about 20 miles above Augusta, but the stream is navigated to a considerable distance higher than that obstruction. Timber is the principal staple brought down either branch of the Kennebec.

Penobscot river falls into the Atlantic Ocean fifty miles north-east from the mouth of the Kennebec. The basin of the Penobscot is 150 miles in length, with a mean width of 55 miles. The sources of this river remain imperfectly known, but reach above north Lat. 46°, and interlock with the sources of Chandiere branch of St. Lawrence, those of St. John's river of New Brunswick and Maine, and those of Kennebec. This basin extends over an area of 8000 square miles. The tide ascends to the town of Bangor, 50 miles above the entrance of the bay. Though draining less surface than the Kennebec and Androscoggin, the Penobscot is more navigable than either, and is considered as the principal stream of Maine. Falls do not immediately occur in the Penobscot at the head of the tide. Boat navigation remains uninterupted 20 miles farther inland. Timber and fish are the chief staples exported from this fine river, the former in immense quantities.

From Penobscot bay to that of Passamaquoddy, in a distance of about 100 miles, a number of small rivers enter the Atlantic Ocean, the principal of which are, Union river, Narraguagus river, Pleasant river, Chandler's river, Machias, and East rivers.

Union river falls into the Blackhill bay, the Narraguagus into Pigeonhill, or Narraguagus bay; Pleasant river into the bay of the same name; Chandler's river into English bay; and Machias and East rivers into Machias bay. None of those streams have sources sixty miles inland, and though in a very remarkable manner supplied with convenient harbours, the inland commerce of the country is very confined.

We have now reached the limit of the north-east boundary of the United States, at the mouth of the St. Croix, or Schoodic river. Important only as a bourn between two nations, the St. Croix is insignificant in every other respect, and, in a survey of the river basins along the Atlantic coast, merits no farther notice, than merely to mention that the Passamaquoddy bay, into which it is precipitated, has depth of water for the largest vessels.

Passamaquoddy bay is only an indenting of that of Fundy, which extends upwards of 120 miles from the north-east angle of the United States, between New Brunswick and Nova Scotia. Towards its extreme head this vast gulf divides into the Chignecto channel, and Basin of Minas, both reaching within a few miles from the strait between Prince Edward's island and the main shore of New Brunswick and Nova Scotia. The tide flows into Chignecto channel with a depth of 60 feet. This unparalleled tide renders the bay of Fundy, with its minor bays and tributary rivers, of extremely difficult navigation, though, from the inequality of elevation and violence of the currents, this inland sea is less encumbered with ice than many places six or seven degrees of latitude more to the south.

Canals have been projected, at many points, to unite the bay of Fundy with the opposite strait, and would be, if completed, a most useful inland route from the St. Lawrence into the Atlantic ocean.

St. John's is the only river of considerable magnitude which enters the bay of Fundy. This noble stream rises in Maine; its extreme northern and north-western sources reaching to within 20 miles of the St. Lawrence. Flowing first to the north-east, then east, and finally south-east and south, falls into the bay of Fundy, after an entire comparative course of 350 miles, forming the largest stream on the Atlantic coast, between the basin of the Susquehanna and that of the St. Lawrence. The tide flows up this stream upwards of 80 miles: its mouth between St. John and Castleton is narrow, and impeded by a ledge of rocks, on which there is only 17 feet water at low tide. The St. John is very difficult of entrance, from the violence and eddying of the tide, and the incumbent mass of fresh water from the river.

The basin of St. John is about 250 miles in length, with a mean width of 100 miles, comprising an area of 25,000 square miles. In its natural state the St. John is one of the most navigable rivers in the Atlantic system, being much less impeded with falls than any other of the streams entering that ocean, between the Hudson and gulf of St. Lawrence. The lands watered by either the main river or branches are also more fertile than that contained in the river basins north-east of the Connecticut. In point of climate the St. John's basin reaches the 48th degree of North Lat. and terminates on the Atlantic coast at North Lat. 45° 10′, extending through near three degrees of latitude.

We now proceed to survey one of not only the greatest rivers of North America, but of the world, the St. Laurence.

As a basin of inland commerce, it may indeed be truly asserted that the St. Laurence stands alone on the globe. The sublime and peculiar features of that unequalled assemblage of fresh water seas demand more than ordinary attention from the geographer and statistical inquirer. This immense basin extends from the mouth of the St. Laurence to the head waters of Lake Superior, 1350 miles, with a mean width of about 400 miles, and containing an area of upwards of 500 000 square miles.

The tide ascends farther in that basin than in that of any other of the known world, or upwards of 400 miles, by comparative courses from the gulf, to about half way between Quebec and Montreal. Above tide water to Ogdensburg, the navigation of the river is much impeded by shoal sand rapids, but is in no place actually impassable with vessels, either ascending or descending. Ships of the line, of the first class, are navigated as high as Quebec, and vessels of 400 tons are taken to Montreal, upwards of 550 miles from the gulf. St. Laurence basin is subdivided into three natural sections, or secondary basins. First, that of Lake Superior and tributary streams; second, that of Lakes Huron, Michigan, and Erie; third, that of Lake Ontario, and the residue of rivers to tide water. Of these in order.

Lake Superior is an immense reservoir, elevated above the level of the Atlantic tides 641 feet,[*] and extending over a square of 300 miles each side, or 90.000 square miles. Of this expanse Lake Superior itself occupies a triangle of 350 miles base, with a perpendicular of 160 miles, or embracing an area of near 30,000 square miles. This greatest fresh water lake of the globe extends from the straits of St. Mary to the mouth of St. Louis river, following the windings of the shore, 400 miles, with from 50 to 150 miles in width. Sufficient depth of water is every where found for the largest vessels. So much of the shore of this lake is rock bound, as to render its navigation in a high degree dangerous, and with the severity of the climate, and sterility of its adjacent shores in most places, will, in a great degree, deprive mankind of the benefits of such a sheet of water so far inland.

Draining 60,000 square miles of land, it must be obvious that an immense body of water is poured into Lake Superior; which, besides innumerable smaller streams, receives, from the south, Bois Brulé, La Mauvaise, Montreal, Iron, and Huron rivers; from the north, Redstone; from the north-west, Grand Portage river; and from the west, St. Louis river.

The inland route to the sources of the Mississippi, and adjacent regions, is by the channel of the latter. The following distances and relative elevations from the Fond du Lac, or mouth of St. Louis river, to the sources of the Mississippi, are extracted from Schoolcraft's travels with Governor Cass[†].

From the mouth of St. Louis river to the South-West Company's House,		24
To the foot of the Grand Portage,	2	26
To the Galley,	2	28
To the head of Grand Portage,	7	35
To the foot of the Portage aux Coteaux,	6	41
To the head of do. do.	1½	42½
To the Isle aux Plaie,	3	45½
To the Isle aux Pins,	6	51½
To the head of do.	½	52
To the foot of the Grand Rapids,	2	54
To the head of do. do.	6	60
To Glukie Rapids	6	66
To head of do.	1	67
To Gros Rocher	21	88
To mouth of Savannah river	12	100
To the portage, from St. Louis river,	24	124
Over the Savannah portage,	6	130
Down another Savannah river discharge into Sandy lake,	18	148
South-West-Company's House on Sandy lake,	3	151

Relative elevations in the foregoing distances:

	Rise in Feet.	
From the mouth of St. Louis river to South-West-Company's House,		4
To the Galley, 4 miles farther,	8	12
To the head of the Grand Portage,	220	232
To the foot of the Portage aux Coteaux	18	250
To the head of do. do.	42	292
To the mouth of the Savannah river,	212.6	504.6
To the Savannah Portage,	18	522.6
To the head of the West Savannah,	30	552.6

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[*] Schoolcraft's travels, p. 261; and this work, Vol. XIII. Part II. p. 627, Article Mississippi.

[†] Schoolcraft's travels, p. 236 and 262.

We thus find the extreme summit level, between Lake Superior and Sandy lake, to be 550.6 feet above the surface of the former, in a direct distance of about 70 miles. If this estimate is correct, the country west of lake Superior has a rise, in 70 miles, of within 90.4 feet as much as from tide water in the Hudson to the head of that lake.

Depression from the summit level to Sandy lake:

	Dep.	Feet.
To first Rapid,		2
Descent of the rapid,	5	7
Head of second rapid,	4	11
Descent of do.	8	19
Thence to the level of Sandy lake,	4 6	23 6

This depression taken from 550 6 feet leaves 527 feet, as the elevation of the surface of Sandy lake over that of lake Superior. Mr. Schoolcraft (page 261) estimates the entire fall from the summit level through Sandy Lake into the Mississippi at 60 feet; and the elevation of the sources of that river, above that of the mouth of Sandy Lake river, at 162 feet.

From these elements we have 36.4 feet fall from Sandy lake into the Mississippi, yielding an elevation of that stream at the mouth of Sandy Lake river, above the surface of lake Superior, of 490.6 feet. If to the latter sum we add 162 feet, we have 652.6 feet as the elevation of the sources of Mississippi river above the surface of lake Superior. We have already found that the latter lake was elevated 641 feet above the Atlantic tides, which sum added to 652.6 produces 1293.6, say in round numbers 1,300 feet, as the elevation of the sources of the Mississippi over the Atlantic tides; (see article Mississippi, page 627, in the note.) In that note it will be seen that Mr. Schoolcraft's deduction does not agree with his elements. He there deduces 1330 feet as the elevation of the Mississippi sources:—But by adding together 641 feet the elevation of lake Superior, 550.6 feet rise to the intermediate summit level between lake Superior, and the mouth of Sandy-lake river, and 162 feet as the rise of the Mississippi river from Sandy-lake river to its sources, we have 1353.6 feet; and this sum, less 60 feet, the fall from the summit level before noticed, to the mouth of Sandy-lake river, leaves as before 1293.6 feet as the real elevation of the sources of the Mississippi.

By the river of the Grand Portage, which enters lake Superior nearly opposite to the south-west end of Isle Royal, a route is opened with the wide uncultivated expanse upon the sources of the Winnepeg, Assiniboin, Red, and other branches of Saskashawin. This is the great thoroughfare of the fur trade.

The enormous surplus mass of the waters of lake Superior are discharged at the falls of St. Mary, North Lat. 46° 31′, by a fall of 22 feet 10 inches, according to the admeasurement made by Col. Gratiot.* The river, or strait of St. Mary's is about 40 miles in length, and connects the upper secondary basin of St. Lawrence with that of Lake Huron, Michigan, Erie, and their confluent waters. The latter basin, depressed below the former 76 feet, spreads over a parallelogram of 500 by 400 miles; or embracing a superficies of 200,000 square miles. Of this extent, lake Huron occupies 20,000 square miles, Michigan 13,500, and Erie 15,000, or over an aggregate of 48,500 square miles. If to this we add 1,500 square miles for lakes St. Clair and Nipissing, other smaller lakes, and the rivers, we have, in round numbers, in the second or middle basin of St. Lawrence, 50,000 square miles of water, or one fourth part of the entire surface.

The middle is the most valuable of the three minor basins of St. Lawrence. In point of climate, it reaches from North Lat. 40° 20′ to North Lat. 47°. The arable surface is unequally divided, as near two thirds of the whole is on the right or United States side of the chain of lakes. It would be needless to enumerate the great number of rivers which every where flow from the adjacent country into the lakes: we will therefore particularly notice only those which from their position have already, or may become noted channels of Inland Navigation.

Of the latter, proceeding from west to east, the first which demands attention is Fox river, flowing into Green Bay, or the north-western arm of lake Michigan. The entire length of this river is 260 miles, 50 of which consist of lakes. It is formed by two branches, the Vaseux, and Portage rivers, which unite 15 miles from Portage from the latter to the Ouisconsin branch of Mississippi. The Vaseux flows in from the north-west, and from its junction with the Portage river to Winnebago lake is 190 miles, following the windings of the stream. In this distance, Fox river in most places resembles a canal or strait more than a river, its current is gentle, and often expanded into lakes of considerable extent. The river here appears to wind across a valley, which is terminated by a ridge of hills crossing between Green Bay and Winnebago lake. The latter opens above the ridge we have noticed, and extends with a width of 5 or 6 miles about 24 in length. The adjacent country has been described as in a peculiar degree fertile and agreeable to the eye.

At the bottom of the Winnebago lake, the river changes its character: the shores become rocky, and precipitous, and the bottom of the stream much embarrassed with falls, rapids, and shoals. By a very circuitous channel of 40 miles, through this mountain pass, the navigation of the river is obstructed by the Winnebago, Little Kakalin, Grand Kakalin, and the Rock rapids. From the foot of the latter to the head of Green Bay is about 6 miles of smooth water. At low water, late in the summer and early in autumn, the navigation of the mountain pass of Fox river is extremely dangerous, difficult, and fatiguing, but during the spring floods may be ascended and descended with ease and safety.

Green Bay extends 120 miles in length, in a direction of north north-east, nearly parallel to lake Michigan, with which it communicates by a wide strait, about 75 miles west from the straits of Michilimakinac. It was through this channel that the first discovery was made of the Mississippi river from Canada, and it has long continued and still remains the principal route from the Canadian sea to the upper waters of the Mississippi. The distance by comparative courses, from the mouth of Green Bay to the Portage, from the Fox to Ouisconsin rivers, is 250 miles, and down the latter stream to its junction with the Mississippi 150 miles: but the distance following the windings of the stream is probably one-third more than by comparative courses, or from lake Michigan to the Mississippi about 530 miles.

The Ouisconsin, though a rapid stream, is unimpeded by either falls, shoals or rapids. . The Portage, from the

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* Schoolcraft's travels, p. 130.

Fox to the Ouisconsin river is one of those singular situations which the interior of America affords, where nature seems to have made preparation for the operations of human intercourse. Both rivers originate about 100 miles to the north of the Portage, but at the latter place they approach to within 1½ mile. The intervening ground, level prairie, over which at high floods loaded canoes are navigated from one stream to the other. This circumstance establishes the fact, of the facility of completing the connection by a short canal, perhaps without locks.*

The next point of contact between the navigable waters of the Canadian sea and Mississippi river, is near the south-west extremity of Lake Michigan. Here the small river Chicago, entering Lake Michigan, heads with the Theakiki branch of Illinois, and, from the nature of the intermediate country, opens at high water a natural, uninterrupted route between those two great sections of the United States.

The following observations and facts were published, two years past, in a common newspaper, but we deem it necessary to republish the whole, as illustrating the subject we are now engaged to discuss.

Whilst engaged in collecting facts to show the direct and remote connections which would be formed by the New-York canals, the subject of a natural communication between the Canadian sea and the waters of the Mississippi, was often canvassed with more or less accuracy, as the means of topographical information was more or less ample, and well authenticated. It has long been reported that a channel did exist at high water, between the south-west bay of Lake Michigan and the sources of the river Plein, (Theakiki,) a branch of the Illinois. Local knowledge upon that section of country has been, and continues to be, very limited; but the fact of an intercommunication between the waters of Michigan and Illinois, is now rendered certain, as far as the mere fact is concerned, though we yet possess no maps whose correctness of delineation can enable us to trace distinctly the interlocking streams. The following communication, however, serves to throw light upon this truly interesting subject, and places the fact of a communication of the natúre we have been reviewing beyond dispute.

" New-Orleans, Dec. 15.

" *Passage by water from Lake Michigan into the Illinois River.*—During the discussions respecting the feasibility and expediency of the New-York Grand Canal, it was asserted, that connecting the lakes with the Hudson, would, in fact, be opening a communication into the waters of the Mississippi, and effecting a route of internal navigation or boating from New-York to New-Orleans. It was asserted, that in the wet season, or during the high stage of the western waters, there was a passage of boats from Lake Michigan into the Illinois river. Most people, we believe, did not doubt the assertion—they supposed that, during some extraordinary season, a canoe of wood, but more probably of bark, had, partly by making its way through swamp, grass, and reeds, and partly by being dragged through the mud, actually effected this wonderful passage; and it proved, that canal connecting Lake Michigan with the Illinois was not very difficult, and some hundred or hundred and fifty years hence might be deemed expedient. The writer of the present paragraph was not long since speaking on the subject to a gentleman residing in New-Orleans, and expressing an opinion similar to the foregoing, when the gentleman said, that in October 1805, he was one of a party who performed this passage, of which he related from memory the following particulars:

'Fort Dearborn, erected in 1804, is situated on the western bank of Lake Michigan, in lat. 42°, at the mouth of a smaller river or bayou, called Chicago, in width from 30 to 40 yards, and at its mouth perhaps 100. Passing through low meadows, it has little current, considerable depth, and is navigable to its mouth. From this fort a detachment of 3 officers (of whom I was one) and 15 soldiers, with an experienced pilot, embarked in a large pirogue, on the 20th Oct. 1805, our destination St. Louis. We ascended the Chicago, without difficulty, from 35 to 40 miles, when, suddenly, this small stream expanded into a lake, its length and breadth, judging solely by the eye, about 3 by 5 miles, without current or wave, the banks flat, and destitute of timber; and we left it on the second day of our voyage, at the western end, through a stream or bayou resembling the Chicago, with a gentle current, but directly opposite course. In the dry season, say three months of the year, the waters of the lake disappear, and there is a portage of from 2 to 3 miles between the great lakes and the waters of the Mississippi. The stream on which we now entered, was called Theakiki, winds its course slowly west, through extensive meadows, and receiving on either side, at every 8 or 10 miles, small auxiliary streams, soon becomes sufficiently enlarged for heavy boat navigation.

'On the evening of the second day we overtook a trading boat belonging to Messrs. M'Kenzie and Forsyth, of the North West Fur company, which had left Fort Dearborn a day or two before our embarkation. She was laden with merchandise for the Indian trade on the Mississippi or Missouri, in burden perhaps fifty tons, navigated by eight oars; we continued in company with her the greater part of the voyage to St. Louis.

'On the fourth day, having run perhaps seventy miles, we reached the junction of the Theakiki with Fox river, the first considerable stream which puts in from the right, and the two united form the Illinois, in breadth one hundred and fifty, or two hundred yards. The next day brought us to the mouth of Kickapoo river, a considerable stream from the left, called the Vermillion. Soon after passing the last river, we came to the Rapids, the greatest obstacle to the navigation of the Illinois.

'Our little craft being crowded with soldiers, by the advice of the pilot, some of our men took the land, and others went on board the large boat, myself and three others, besides the pilot, continuing in the pirogue. The river is here narrow; its bed and sides consist of irregular broken rocks, the current rapid, but no where, I think, so rapid as to arrest the ascent of a light boat, impelled by a strong force. Both the boats passed without accident, and at the foot of the rapids we waited for the party on land, who started early in the day, and joined us about dark.'

" Here concludes the account which this gentleman was so obliging as to afford, and which, allowing the inaccuracies of memory, and optic measurement, may serve to give us a good general idea of this interesting and important communication between the waters of the north-east and the south-west. The Illinois, it is well known, is one of the most navigable of our western rivers. Nothing more seems necessary to render this communication useful to commerce, than to deepen the passage from the Chicago to the Theakiki—the rapids of the Illinois would not, probably, need to be locked. Where a boat of 50 tons, unwieldy, and carried alone by the current, could pass in safety, the stream would be navigable for a steam-boat of much larger burden. Thus easy would it be, in conjunction with the Grand Canal, to open a chain of internal communication of between 2 and 3000 miles in length."

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* Schoolcraft, p. 363.

The two following lists of land and water stages from New-York to St. Louis, by the Ohio and Illinois routes, will exhibit the relative distances at a single glance:

Route from the city of New-York to St. Louis, by Hamilton, Pittsburgh, Cincinnati, Louisville, and the Ohio and Mississippi rivers.

	Miles.	
Newburgh		60
Cochecton	60	120
Hamilton	200	320
PITTSBURGH	261	581
Steubenville	59	640
Cincinnati	363	1003
Louisville	131	1134
Mouth of Ohio	393	1527
ST. LOUIS	198	1725

Route from the city of New-York to St. Louis, by Albany, Buffalo, Detroit, Michilimakinac, lake Michigan, Illinois, and Mississippi rivers.

	Miles.	
Albany		143
Canandaigua	213	356
Buffalo	92	448
Erie	90	538
Cleaveland	90	628
DETROIT	110	738
Fort Gratiot	67	805
Michilimakinac	190	995
Mouth of Chicago river	280	1275
Head of Illinois do.	40	1315
Mouth of do.	400	1715
ST. LOUIS	30	1745

It will be at once seen, by an inspection of this table, that the difference in distance, by the two routes, is trifling; and, all things considered, no great diversity exists naturally in the facility offered, or impediments opposed to mercantile transportation; but with the Grand Canal from Albany to Buffalo, the advantages are obviously in favour of the northern route.

Canal communication between Lake Michigan and Illinois river, must speedily follow the advance of population into that section of country.

A number of rivers of considerable magnitude enter the eastern and south-eastern shore of Michigan, by the channels of which a considerable commerce must be carried on, as settlement and wealth increase. Of these the St. Joseph heads, with the Maumee falling into the head of Lake Erie, and with Wabash flowing into Ohio. The intermediate country has not, however, been surveyed with sufficient accuracy, to permit us to determine how far nature has prepared the way to enable man to complete the entire navigable communication from any one water to any of the others.

The Maumee is a river deserving very particular notice, in a survey of the inland navigation of the United States. This river has its sources on the table land, between Lakes Michigan and Erie and the Ohio river, interlocking its branches with those of Miami, Wabash, Illinois, and St. Joseph. On this extensive flat table land the streams are sluggish, and only gain current by reaching a more inclined descent. Such a construction of country is, in an eminent manner, calculated to facilitate the formation of canal and lock navigation.

Maumee is formed by three branches; the St. Joseph's, interlocking with the sources of the river of the same name flowing into Lake Michigan; the St. Mary's, the sources of which rise with those of the Wabash, and Miami, flowing into Ohio; and the Auglaize, heading with the Miami. From the earliest settlement of Canada, the peculiar structure of the intervening country, between the heads of the foregoing rivers, struck every traveller; and at the present moment, when the Indian title to the soil is extinguished, and an active civilized population must rapidly arise upon its surface, the abundant natural resources for inland commerce will be called into active operation.

The St. Joseph's and St. Mary's branches of the Maumee unite near the west boundary of Ohio, but within Indiana. Turning to north-east, the united streams flow in that direction, by comparative courses, about 100 miles, and fall into the extreme south-western angle of Lake Erie. The current is in general rapid, though the bed of the river, except in one place, is unincumbered with shoals or falls. That exception occurs near Fort Meigs, 20 miles above the mouth, where a ledge of rocks crosses the river, and produces shoals for 14 or 15 miles along the stream. The entire depression of the river at this obstruction has never been determined accurately, but is not supposed to exceed 100 or 150 feet perpendicular. A bar crosses the mouth of Maumee river, over which there is not above 7 feet water. A glance upon a map of the entire region between Ohio river and Lakes Michigan and Erie, can scarcely leave a doubt but that the channels of Maumee, Wabash, and Miami, must become the great lines of inland navigation between the Canadian sea in that quarter, and the valley of Ohio. The distance from Lake Erie to the head of boat navigation in Maumee is, as has been observed, 100 miles by comparative courses. By a similar mode of admeasurement, the navigable channel of the Wabash is 250 miles, making the entire channel from Erie to Ohio of 360 miles; which, by adding one-third for the particular bends of the rivers, will yield an inland route of 480, say in round numbers 500 miles. The entire portage between the naturally navigable points of the two rivers is not quite 5 miles. The other route, through the Miami, is 200 miles shorter than the former; but striking the Ohio 360 miles higher, following the bends of the latter river, and also with a much wider intervening portage, the Miami channel offers much fewer advantages than that by the Wabash.

The next navigable route from Lake Erie to Ohio river, after the preceding, is through the Sandusky and Sciota rivers. The latter is a very direct line of intercommunication, of about 300 miles, following the bends of the streams, 100 of which are in the Sandusky and intervening portage of about 20 miles, and 200 in the Sciota. The country between the sources of Sciota and Sandusky is flat, and in spring floods in great part overflown. The portage, as already observed, 20 miles between the naturally navigable waters of those two rivers. The navigation of Sandusky, like that of the Maumee, is impeded by rapids and falls before reaching Lake Erie, but is otherwise suitable for the conveyance of boats of considerable size.

Hitherto the confluents of Ohio river are without falls or dangerous rapids. The Wabash, Miami, and Sciota, are sluggish streams near their sources, but become more rapid in their progress towards their common recipient. They are all, at seasons of high water, navigable to very near their sources, and flow through a highly fertile country.

From the advance of population, and from the near approximation of the Ohio river to Lake Erie, the channels of Cayahoga and Tuscarawas branch of Muskingum have been chosen by the legislature of the state of Ohio, as the route of a navigable canal to connect the Canadian sea to the valley of Ohio.

The Cayahoga river rises principally in Portage and Geauga counties in Ohio, and flowing fifty miles south-west, reaches within ten miles from the navigable waters of the Tuscarawas. Already a fine boatable stream, the Cayahoga, turns at an acute angle near the village of Northampton, and flows in a direction of north north-west about 40 miles, falls into Lake Erie in Cayahoga county, at the flourishing town of Cleveland.

The Tuscarawas rises in Wayne, Medina, Portage and Stark counties, and forming a large navigable creek in the latter, flows south south-east 30 miles, receives Sandy creek from the east, and 12 miles still lower, Sugar creek, from the west near New Philadelphia. Below the latter place the Tuscarawas curves gradually south-east, south-west, and finally west, flows 50 miles to its junction with Whitewoman's river at the town of Coshocton. The two rivers at their confluence are nearly of equal size, and are both lost in the general name of the Muskingum. Assuming a southern course of ten miles, Wills creek enters from the south-east, and winding more to the west, 30 miles farther, receives Licking creek, a large tributary branch, at the town of Zanesville, in Muskingum county. Here the river is precipitated over its only falls, or rather rapid, 30 or 40 feet entire depression. Below the falls, Muskingum turns to the south-east 80 miles, to its junction with Ohio river at Marietta, in Washington county.

From this sketch, we find this inland channel lying in nearly a north and south direction. Advancing from Cleveland on Lake Erie, up the Cayahoga 40 miles, we reach the Portage, from that stream to the Tuscarawas; thence ten miles over that portage, and again down the Tuscarawas and Muskingum 212 miles to Marietta, exhibits an entire line of 262 miles. As this is probably the first route of inland navigation to connect the river systems of Mississippi and St. Lawrence, which will be completed by act, it will be necessary to take particular notice of the steps already taken to carry those improvements into effect.

In 1814 the legislature of Ohio granted corporate powers to a company for the purpose of cutting a canal and constructing locks around the falls of the Muskingum at Zanesville. The necessary expenses of the works are calculated at from 70,000 to 100,000 dollars. The undertaking is in rapid progress, and will no doubt be soon completed. The adjacent country abounds with exhaustless beds of mineral coal, and the water power afforded by the falls renders the vicinity of Zanesville one of the most favourable manufacturing sites in the valley of Ohio. Independent of the communication between the Tuscarawas and the Canadian sea, the canal and locks past the falls of Muskingum will open to the Ohio trade an expanse of country having an area of about 8,000 square miles.

The following papers are extracted from Col. Charles G. Haines's able collection of documents respecting the canals of New-York in particular, but incidentally upon the policy of constructing artificial water communications throughout the United States in general. We have made the extracts as illustrative of the incipient progress made in the state of Ohio to unite the waters which bound that state on its northern and southern borders. In the language of Col. Haines, "these letters, and the essay with which they are accompanied, cast much light on the second great Western Canal. They will be read with deep interest in the nation, and out of the nation."

Columbus, Sept. 20th, 1820.

Charles G. Haines, Esq.

Dear Sir—I have been prevented by business, and a desire of communicating more satisfactory information, from sooner acknowledging the receipt of your letter of the 4th of August.

You give great pleasure, by informing me of the interest felt in the state of New-York, in regard to the commencement and completion of a canal from the Ohio river to Lake Erie.

Young as our state is, and forced hitherto to rely, almost exclusively, on direct taxation, for public improvements, as well as for the support of government, we look to your state for capital, in the first instance, towards effecting this object, either by way of loan, should the work be undertaken by the state, or for individual subscription, should it be thought necessary to incorporate a company for the purpose.

I should be much obliged by the views that may be entertained by any members of your association, concerning the prospect of raising these funds in New-York, in either of the abovementioned alternatives; to the latter of which, I confess, I feel a repugnance, while a hope can reasonably be entertained, that the work will be accomplished by the state.

You are pleased to observe, that "the command of public opinion will be the command of financial resources;" this is very true, but, even in the rich state of New-York, it requires time, patience and perseverance, to acquire that command; by proofs heaped upon demonstration, when a vast enterprise, of a nature still new to this country, was proposed; and we are greatly indebted, here, for your daring experiment, inasmuch as it may lead, by force of its great example, to an investigation of what latent resources Ohio may possess.

You first enquire whether it be practicable to connect Lake Erie with the Ohio, by means of a canal?

The House of Representatives of our legislature addressed to me last winter a similar inquiry, in answer to which, I communicated what information I then possessed on the subject; a copy of this message, to which I beg leave to refer you, is forwarded by this post. The intelligence I have since acquired on this head is favourable. One of the public surveyors has since assured me, that, in the dry season preceding, he found the two eastern branches of the Sandusky that issued from the Morass, mentioned in that paragraph of the message marked A, to afford each a supply of water sufficient to turn a large run of mill-stones, by an undershot wheel. There seems no doubt, that these can be diverted into the Scioto. On the other hand, a more correct examination has proved, that the little Scioto, at the place mentioned in the same paragraph, is elevated seven feet above the Sandusky. I have no further information of the supply of water, for the route through the valley of Mad river, nor any thing to add concerning the practicability of a water communication through the north-eastern part of this state, and part of Pennsylvania.

Your next inquiry relates to the distance, the fall, and number of locks required?

I can only answer the first, as regards geographical distance: The length of the canal must inevitably depend on the course which the face of the country will compel the engineer to pursue; and this is not likely to be so sinuous as the western canal. By the road (tolerably direct) from Sandusky Bay, to the mouth of Scioto, the distance is about two hundred miles: From the bay to Cincinnati, by a road less direct, about ten miles less. In relation to the fall, I have to observe, that the survey made by Mr. Briggs from the tide water in James river, in Virginia, to the mouth of the Kenahawa, shows my conjecture to be nearly correct, concerning the comparative elevation of the lake, and of the Ohio, at the mouth of the Scioto. I should presume, that at Cincinnati, the river must be at least 40 feet lower.

The survey alluded to in paragraph C, was from the level of the bay, in a direction towards the heads of the Great Miami and Mad rivers. In the opinion of many judicious persons, there must have been some error in this survey; although the summit in that course must be considerably higher than in a line northwardly from this place, where the Scioto flowing from the west, and branches of the Sandusky from the north-east, approach each other; and from whence each river bends its course to an opposite point of compass from the other. The reason for supposing this error, is chiefly grounded on the circumstance, that the principal rapids of the Sandusky are within 18 or 20 miles of the level of the lake, and have been surmounted by canoe navigation; while above them, from its most southern bend, the current of the river is represented as very gentle.

I perceive that the New-York newspapers (probably on the authority of Mr. Steele) represent the summit between Sandusky and Scioto as elevated 300 feet above Lake Erie; I think it probable that this approaches the truth.

You will be more competent to judge of the number of locks that may be required than I am.

Your third inquiry concerns the leading advantages of the canal to the state of Ohio, and to the country bordering on the lakes, on the completion of the great western canal, from Erie to the Hudson?

Among the principal benefits which may first be expected to be derived from the completion of these works would be the importation of salt, iron, and some other heavy, but indispensable commodities, not yet produced here in sufficient quantities; besides the diminished cost of transportation of various articles of merchandise, consumed among us, and for which a large portion of the western country would resort to the market of New-York —a trade which heretofore has been, in a great measure, the life of Philadelphia and Baltimore.

If lateral and diverging canals are to be formed (especially towards the Muskingum) the importation of gypsum for manure might, at no great distance of time, become an item of great importance: but, the greatest advantage we should expect, would be the easy and cheap conveyance, to your grand mart, of our agricultural productions; which, under an imperfect cultivation by a population still thin, are already immense. The region in the south-western part of this state, called the Miami country, is one of our most fertile, best cultivated, and most populous districts. From one county within it, containing about 400 square miles, my correspondent last winter acquainted me with the result of his inquiries into its product, as follows: Harvested last season, (1819) 246,000 bushels of wheat—43,500 bushels of rye—463,000 bushels of corn. In the winter preceding, I was informed, that the same county had prepared, and chiefly sent off, 4,000 hogs for market. This kind of stock is almost uniformly driven to the lake, or to the Ohio, to be slaughtered, by way of saving expense, in the carriage of salt pork and bacon. Of the proceeds of their dairies, and considerable numbers of neat cattle and horses reared in this county, I have no returns. This county may be assumed as the average of what is severally produced by 7 or 8 others, all nearly of the same dimensions, in the quarter above mentioned.

The average cost of land carriage, to places where these provisions can be embarked, on the Ohio or the lake, is scarcely to be reckoned less, even in these dull times, than from 50 to 75 cents per hundred, through the year. It is true, that much of this cost of land carriage is occasionally saved in this state, by transporting on the principal streams that cross different parts of Ohio; but this navigation is not without considerable difficulties and dangers, and is, withal, so uncertain, depending on the rise of the waters (which, after all the preparation of adventurers, sometimes fails of their expectation) that it forms an increase of expense.

North and west of Chilicothe, lies the most fertile part of the country on the waters of the Scioto—extensive and beautiful in a high degree, to the eye of the farmer, but more lately settled, less populous, and in general much less cultivated, than the Miami country. The small county, however, contiguous to this in which I am writing, has, for successive seasons, produced far greater wheat harvests than have ever been gathered in any of the more western counties, and of corn perhaps nearly equal. Land carriage has heretofore been $1 50 per hundred between Columbus and the Ohio river, and more to Sandusky bay.

Of the country on the lakes, I know nothing personally, except our own coast of Lake Erie. Governor Cass and the secretary of Michigan, Mr. Woodbridge, are persons whose intelligence and active zeal in discovering what concerns their territory will enable them, better than any one known to me, to satisfy you, of what advantages would be likely to result to the countries bordering on the Detroit, and lakes Huron, Michigan, and Superior, from the accomplishment of these great canal communications.

The settlement of that part of this state, bordering on the lake, is considerably more recent than that near the

Ohio, and much less of its forests have yielded to the hand of improvement. That portion of territory known by the appellation of the 'Connecticut Western Reserve,' as well as most of the land (not yet sold) lying west of it, is in general less a grain, than a grazing country, which may partly account for a slower progress of settlement, till within a few years, during which it has rapidly increased, in population and improvement, and the inhabitants exhibit a great deal of public spirit, in promoting and accomplishing works of public utility. Iron ore is abundant in various parts of the reserve. They have yet few forges or furnaces. Their search for salt has been less successful, and I anticipate that for this article they must depend on New-York. Coal has not been discovered in any considerable quantity near the lake; but it is understood, that inexhaustible beds of this mineral are found in the south-eastern part of the reserve, and touching on the probable route for a canal in that quarter, adverted to in a preceding part of this letter.

Your last question requires an account of what lateral canals can be connected with the Ohio canal?

I am unable to answer this question by any conjecture of tolerable accuracy. I believe there are several practicable, of greater or less extent. At present, I dare not venture to add any thing to the hazardous remark contained in paragraph D, of the message, so often (and I fear so fatiguingly) referred to.

You will observe that there is a part of the communication transmitted to you at this time relative to a financiering plan, irrelevant to the subjects of your inquiries. Our legislature passed an act at their last session proposing to purchase from the United States, from one to two millions of acres for the object of a canal; and for a survey, and estimates, in case the proposition should be agreed to. It was not accepted by congress, not that the price offered was insufficient, or that the security would in other circumstances be objectionable, but on the principle, as I understand, that it is impolitic for congress to give credit to a state, or for a state to become indebted to the United States, on any terms or conditions, or for any purpose whatever. A bill, however, passed the senate, providing for a survey, &c. which now lies among the unfinished business of the house of representatives. Unsuccessful in this attempt—uncertain what may be the disposition of congress at their next session, and the aspect of affairs among us rather gloomy, from the depression of our agriculture, we are compelled to view the accomplishment, and even the commencement, of the Ohio canal, as more remote than our own sanguine wishes had once imagined it to be. But I cannot consent to lose sight of it, while its practicability remains probable. Patience and perseverance may at length prevail: diligent investigation may, I trust, devolve dormant resources in our state; its government is free from debt, its credit, (yet untried abroad) may prove good; but our legislature must be well convinced, before they consent to pledge that credit in a new scheme of immense magnitude.

It is to me a source of regret, that I have not possessed the means, to afford you information more exact and satisfactory. I have taken measures, which, I hope, will be effectual, to enable me to digest several statistical accounts and estimates of the nature and quantity of our productions, in agriculture and manufactures. If I succeed according to my hopes, I shall have it in my power to furnish you, in the course of next winter, with more precise and certain answers to some of your queries. After the polite invitation I have received, to contribute to the general stock of information, on the great subject of the internal trade and navigation of the country, it would be ungrateful, and argue a want of patriotism in me, should I withhold from you and the association, what knowledge on the subject I possess, or may acquire. If any thing valuable can be culled from this communication (too imperfect in matter and manner for publication) I shall be proud to have furnished it; and I still indulge the hope of being able, in a few months, to offer you a statement on some of the points of your inquiry, more certain and therefore more worthy of their acceptance.

I am, Sir, with great esteem,
Your obedient servant,
ETHAN A. BROWN.

New-York, August 1st, 1821.

CH. G. HAINES, Esq.

SIR—I have received your note of this date, on behalf of the New-York corresponding association for the promotion of internal improvements, requesting information as to the practicability and probable expense, of making a canal across the state of Ohio, from lake Erie to the Ohio river.

In answer to your inquiries, I will refer you to an essay on the subject of the contemplated canal across Ohio, (which is herewith transmitted to you) which I transmitted to Governor Brown, of Ohio, and which was by him laid before the legislature of that state at their last session. The ideas contained in that essay were hastily thrown together during severe indisposition; but I have every reason to believe that they may be relied on as correct.

The completion of the Erie and Hudson canal, and the Erie and Ohio canal, will produce a complete revolution in the trade of a considerable portion of the western country. It will cement the eastern and western states together by the strongest ties; and if similar improvements are made throughout the United States, we need not dread a separation of the American union, which no American can desire to behold; and I wish that the generation that witnesses its dissolution may witness also the world wrapt in flames.

With sentiments of esteem,
I am yours, &c.
W. STEELE.

The following considerations on the project of a canal, to connect Lake Erie with the Ohio river, were submitted to the legislature of the state of Ohio in 1820, by W. Steele, esq.

"Nothing can be of more importance to the state of Ohio, than the making a navigable canal from Lake Erie to the Ohio river. That it is practicable to make such canal admits not of a doubt. Were it made, and the Hudson and Erie canal finished, we should have an easy and cheap highway on which to transport our surplus produce to the New-York market. I have had the levels taken at three different places, from the summit level between the Scioto, and the Sandusky, to the head of Sandusky bay, at Lower Sandusky. From the summit level on the most favourable route for a canal that I am acquainted with to Lower Sandusky, the descent, agreeable to the report of Mr. Farrer, whom I employed for the purpose of taking the levels, is 318 feet. Mr. Farrer had good instruments, and I presume that the levels are taken with tolerable accuracy. By the report of the engineers employed by the state of Virginia, they make the Ohio river, at the mouth of the Great Kenhawa river, 83 feet lower than lake Erie. If those levels are to be relied on, and we ascertain what is the amount of the descent in the Ohio, from the mouth of the Great Kenhawa to the point where the canal is intended to communicate with the Ohio, we will then know what will be the whole amount of lockage required. If we allow 50 feet for that descent, the lockage will be as follows: From Lake Erie to the summit level 318 feet: From the summit level to the Ohio 433 feet, making the whole amount of lockage 751 feet. The estimate by the commissioners for making the New-York canal is $13 800 per mile. Owing to the reduction in the price of labour, it is found that it can be made for much less money. The ground for making a canal across the state of Ohio, is much more favourable than that over which the New-York canal is now making. And although there would be more lockage on the Ohio canal than on the New York canal, yet it is believed that it can be made at less expense than an equal distance of the New-York canal. There would not have to be that heavy expense incurred in excavating rock that is encountered on the New-York canal. When we take into consideration the low price at which labour can be had, and the advantage to be gained by the employment of experienced engineers, now employed on the New-York canal, I think I hazard but little in saying that a canal can be made across this state for $12,000 per mile. If we suppose the canal to be 200 miles long, at this rate it will cost 2,400,000 dollars. I am aware that some will say that the state of Ohio is too young and too poor to undertake this mighty project. But I deny that the state of Ohio is either young or poor. She contains at this time more than 500,000 souls, and ranks the 4th or 5th state in the Union. Can a state with such a population be young? can a state with such a population (of industrious people too) be poor? It has been justly remarked, " That population is power, and industry is wealth." So I contend that we are both powerful and rich. If the whole line of the canal was divided into feet, it would not make (admitting its length to be 200 miles) 13 1-2 to each man in the state subject to militia duty. The enquiry by some will be, how is the money to be raised to dig this mighty ditch! Raise it in the same way the state of New-York does—borrow it on the credit of the state. Many there are, I have no doubt, who will doubt whether money can be borrowed on the credit of the state: To such I would say, go and try. If we stand at the base of a hill and look up without making an effort to ascend we will never reach its summit, and it may be fairly estimated, on the completion of the canal, it will produce a revenue that will discharge the interest, and enable the state to pay large annual instalments of the principal debt; and in addition to the instalments, in a few years, defray the whole expenses of the state government. The amount received for toll could be expended in making the canal; so that, although it cost 2,400,000, yet it might not be necessary to borrow any thing like that sum. The distribution of the sum of money that the canal would cost among the people of this state would give them more relief from their present pecuniary embarrassments, than can be had from any laws that may be enacted for that purpose.

As the lands in the vicinity of the canal, belonging to the general government, would be greatly enhanced in value, I think it not improbable that congress will make a donation to the state of a body of land in its vicinity, so far as it passes through their territory; if so, it would aid very much in making it. The celebrated Brindley, the greatest engineer that England, or perhaps the world ever produced, Mr. Philips, in his history of inland navigation, says, " Having spoken of various circumstances of rivers before a committee of the House of Commons, in which he seemed to treat all sorts of rivers with great contempt, a member asked him for what purpose he apprehended rivers were created. After considering a moment before he gave his answer, replied, to feed navigable canals." Such was the opinion of this great man, and such indeed must have been the opinions of many others; for we find canals in Great Britain, in many places, running parallel with navigable rivers. Persons unacquainted with the cheap rates at which goods are transported on canals, are surprised when they learn that a ton weight can be transported at the rate of one cent per mile. The illustrious Fulton, but a short time previous to his death, gave it as his opinion that goods could be transported on the New-York canal, when completed, at the rate of one cent per ton per mile. We find him supported in this opinion by Charles G. Haines, Esq. " Corresponding Secretary to the New-York Association for the promotion of Internal improvements." Col. Haines' situation enables him, on this subject, to form correct opinions; his opinions on any subject are entitled to great respect. Mr. Philips, in the preface to his history of inland navigation, says, " All canals may be considered as so many roads of a certain kind, on which one horse will draw as much as 30 horses do on ordinary turnpike roads, or on which one man alone will transport as many goods as three men and eighteen horses usually do on common roads. The public would be great gainers, (he further adds) were they to lay out upon the making of every mile of canal, twenty times as much as they expend upon making a mile of turnpike road."

Sutcliff in his treatise on canals says, " That within the last 25 years there has been expended on canals in England more than $130,000,000."

A country is never made poorer by making internal improvements, even if the people are taxed to make them. If money be taken from the people, it is again paid out among them, and kept in circulation. Were the canals through Ohio and New-York finished, I have no doubt but that two-thirds of the surplus produce of all the country watered by the Ohio, and its tributary streams above the Falls, would pass through them to the New-York market. That it would be the interest of every shipper to give the preference to New-York is obvious. You have there a healthy climate, where, if you think proper to store up your produce, you can do it in safety. Not so at New-Orleans; if you there store up perishable articles, they may be considered next to lost. The amount of produce that perishes on the way to, and at New-Orleans, every 15 years, would itself more than pay for building a canal across the state of Ohio. During the spring tides, when the principal part of the produce of the western country is carried to New-Orleans, that market is glutted, and the shipper is very often pleased at being able to return home with half the money his cargo cost him.

If Mr. Fulton's estimate as to the expense at which goods can be transported on canals be correct, the expense of transporting a barrel of flour to the city of New-

New-York (allowing ten barrels for a ton) will be as follows:—

	Miles.	Cents.
From the Ohio to lake Erie .	200	20
Down lake Erie . . .	260	20
Through the New-York canal .	353	35
Down the Hudson to the city of New-York	160	15
Total	973	90

To this must be added the tollage through both canals.

The lowest rate at which flour is at present freighted to New-Orleans from the falls is $1 25 per barrel. Nor is it probable that the price will be reduced, as the boats, which cost from 100 to 150 dollars, are generally thrown away at New-Orleans, or sold for a sum not exceeding the tenth part of their cost. Opportunities but seldom offer to ship in steam-boats, owing to the difficulty of passing the falls. It will be recollected, that while our produce is carried to New-York, at the cheap rate quoted above, that our foreign goods can be brought through the same channel at the same rates (whereas, at present, the expense of transportation costs from 3 to 5 cents per lb. or from 67 to 112 dollars per ton.) More or less of these goods the people will have, and the cheaper the rates at which they can be furnished, the better for the country. And besides, it must be recollected, that if they are brought across the mountains by way of Pittsburgh, or from New-Orleans, by way of the Mississippi and the Ohio, that the expense of transportation is paid to the citizens of other states. If they are brought through the Ohio canal, the money saved in the state thereby would, in twenty-five years, amount to more than the whole cost of the canal. It must be admitted that the risk on the canal and lake, is much less than on the Ohio and Mississippi, and the time required to carry the produce that way much less.

By turning the trade from New-Orleans to New-York, we would save thereby, the lives of many of our most enterprising and useful citizens, who would otherwise fall victims to the diseases of the lower Mississippi. The state of Kentucky has lost more of her citizens by the Orleans trade within the last fifteen years, than she has lost by the late war, and it is known she bled at every pore.

Lateral canals may be made from the main canal in many places, which will serve to collect to the main canal the rich products of the soil through which they pass, and at the same time afford means of furnishing the country with many of the necessaries of life, at prices greatly below what they now cost, or ever will cost, without the canal. I will only name the article of salt, which, by means of the canal, may be furnished to the people in the interior of the state, from the Salines of New-York, at a price, but little, if any thing, exceeding fifty cents per bushel. It is impossible to calculate what will be the benefits that may be derived to the people of this state by the making of the canal. In its progress, it will, no doubt, lay open rich beds of minerals. It will lay us, as it were, along side of the Atlantic. It will, in short, elevate the character of the state, and put it half a century in advance of her present situation.

And I would respectfully inquire whether the convicts now in the penitentiary might not be more usefully employed in making a canal, than at work in the penitentiary?

It only remains for the legislature of Ohio to apply the means within their reach to accomplish this desirable object. When accomplished, there can be no doubt but that it will produce a sufficient revenue to defray the expenses of the state government for ever.

By a letter of the 11th of March, 1822, from James Geddes, Esq. one of the engineers upon the New-York canals, to the author of this article, the people of Ohio have voted a sum of money for the purpose of exploring the foregoing route. "The acting governor, Allen Trimble, Esq. has written to Governor Clinton, requesting that an engineer from that state (New York) would undertake the task of exploring." Mr. Geddes intimates an intention of obeying the requisition of Governor Trimble.

It would be needless to notice the suggested route of water communication between lake Erie and the Ohio valley, through Big Beaver river, or the branches of the Allegheny river, as the elevation of the intermediate ground precludes any rational hope of effecting canals to a profitable issue in that quarter. We, therefore, close our observations, in this place, upon the United States' side of the middle basin of St. Lawrence, and refer the reader to our review of the New-York canals, for our concluding remarks upon that subject.

If we turn our attention to the Canada side of the St. Lawrence middle basin, we perceive a long triangular peninsula, bounded south-east by lake Erie, Niagara strait, and lake Ontario, on the north-west by the Detroit river, lake St. Clair, St. Clair river, and lake Huron, and on the north-east by Black river of lake Huron, lake Simcoe, a chain of small lakes leading into the head of the river Trent, down that river into the bay of Qninté, and by that bay to its mouth, into the north east part of lake Ontario. This peninsula, of 280 miles in length, by a mean width of about 80, or embracing an area of 22,400 square miles, is partly in the lower, but mostly in the middle St. Lawrence basin.

Through the chain of lakes and rivers extending from lake Ontario to Gloucester bay of lake Huron, an inland route already exists, with only one short portage, which abridges the distance from the head of St. Lawrence river at Kingston, to lake Huron, one half; it being only 300 miles from the latter to lake Ontario, by the Quinté and lake Simcoe route, and between 600 and 700 by lake Ontario, Niagara river, lake Erie, Detroit, and lake and river St. Clair.

The peninsula is the best peopled part of Upper Canada, and in the advance of population and wealth, the improvement of the Quinté, and Gloucester bay channel, of inland commerce, must follow in the very nature of human affairs. This channel has some other pre-eminent advantages over that by the great valley of the Canadian sea. The former avoids the falls of Niagara, and the dangerous navigation of lakes Ontario, Erie, and St. Clair.

We have now reached the lower or inferior basin of St. Lawrence. This immense country extends from north-west to south-east 700 miles, with a mean width of 300, or over a superficies of 210,000 square miles. Of this vast expanse, the United States possess only a strip 350 miles in length, by 70 miles mean width, or an area of 24,500 square miles, leaving 185,500 square miles in Upper and Lower Canada.

In the Niagara strait, from the surface of lake Erie to that of lake Ontario, in a distance of about 28 miles, a depression takes place of 334 feet. Of this depression, the stages are:—From lake Erie to the head of the rapids

15 feet; in the rapids, 51 feet; in the falls of Niagara, 162 feet; from the falls to Lewistown, 104 feet; and from the latter place to the surface of lake Ontario, 2 feet.

Lake Erie is within a trifling fraction of 565 feet above the Atlantic tides; of course, 565 less 334, or 231 feet, is the elevation of lake Ontario above the same tides.

The following papers afford most invaluable information upon the obstructions to the navigation of St. Lawrence river. The author of the communication to the Treasury Department, politely furnished the author of this article with a copy, for the use of his geographical disquisitions generally. They are now, for the first time, laid before the public.

Treasury Department, 11th June, 1818.

Sir—During the last session of congress, a resolution was adopted by the house of representatives, directing the secretary of the treasury to report, at the next session, a plan for the application of such means as are in the power of congress, for making roads and canals.

The survey which has been lately made under your direction, of the river St. Lawrence, from the Canada line to the Ontario, will, no doubt, furnish the data necessary to determine whether the improvement of the navigation of that river can, with propriety, enter into the plan required by the resolution. I have been informed that individuals have already constructed locks, and cut canals upon that river, which have greatly improved the navigation; and that an expenditure of less than one hundred thousand dollars will render it perfectly secure, in its whole extent within the United States. If you can, consistently with the discharge of the important duties imposed upon you by your present appointment, give me such information as will enable me to judge of the propriety of embracing the St. Lawrence in the report to congress, required by the resolution, you will not only greatly oblige me, but perform an important service to the nation, and especially to the inhabitants of that part of the state of New York.

This information will, it is presumed, embrace the number and length of the general canals, and the number of locks which have already been constructed—the fall in the river which is overcome by them—the fall which remains to be surmounted by canals and locks yet to be constructed—the dimensions of the canals and locks constructed, and the expense at which they have been made. Any other information of the same nature, which you may be able to communicate in the course of the summer, will be highly acceptable to the department.

I remain, with respect, your most ob't serv't,

Wm. H. Crawford.

Col. Samuel Hawkins.

Hon. W. H. Crawford,
Secretary of the Treasury.

St. Regis, 27th Oct. 1818.

Sir—I have deferred answering your letter requesting information in relation to the navigation of the river St. Lawrence, as I could not lay before you all the facts necessary to a full and clear understanding of the subject until now.

That you may have a critical knowledge of the various obstacles to an easy and safe navigation along our shore, upon this river, I herewith transmit a sketch composed from authentic materials.*

The first obstruction originates on our side, 3 miles and 1320 yards above St. Regis. Here, for a distance of 440 yards, the velocity of the current is 5 miles per hour; but the water being deep, and near a lime-stone shore, its navigation can be sufficiently aided by the erection of a towing path, at an expense of about 300 dollars.

The next rapid, of any consequence, is the strait separating Massena point from the head of Cornwall island. The current runs through this strait, for more than 800 yards, at the rate of 8 knots per hour; but the bank is so formed at this place, that the navigation may be rendered entirely convenient by a towing path, at an expense of about 700 dollars.

About one mile and a half above Mersena point, commences a series of rapids, generally denominated "*The Long Sault Rapids.*" For this distance navigators avail themselves of several bays formed by the incurvity of the shore, and a current to propel boats of the largest class, by setting poles and oars On arriving at point Ellicott, 9¾ miles from St. Regis, a very strong current is met, running, for the distance of a mile above, at the average velocity of 11 knots per hour. After doubling this point, boatmen find relief from a small basin of still water, extending upwards a few rods. The difficulties of the navigation at these rapids may be overcome by a well constructed towing road, the expense of which would not exceed 1000 dollars.

A reflux, or eddy, renders navigation very easy from the termination of the last proposed path, to *Sturgeon Point*, nearly opposite to Long Sault island, and 14 miles from St. Regis. Here boats encounter a violent rapid, called by the Canadians *La petite Chûte*, in contradistinction to *La grand Chûte*, upon the opposite side of the river. From the foot of the former rapid, for 890 yards, and upwards, the current rushes at the rate of 16½ miles per hour. This is considered as the most difficult passage for all boats or vessels ascending between St. Regis and lake Ontario; and to render it practicable, (without the aid of locks,) it will be necessary to have a towing path of nearly a mile in length, of sufficient strength to resist the shocks of the descending ice, and wide enough to allow two or more horses to be employed at the same time in dragging boats against the stream. As a great portion of the materials necessary for this work must be brought from a great distance, the expense will be enhanced. I should suppose the completion of this work would require an expenditure of about 5500 dollars. But to render the navigation of *La petite Chûte* permanently good, I should recommend a well connected line of locks.

After passing Polly's bay, another rapid of considerable velocity occurs at Store's point. A towing path will be required here 1220 yards in length, and will probably cost 750 dollars.

At Pepper mill point, 17 miles 587 yards from St. Regis, is a short, but very strong rapid: this may be rendered navigable by a towing path at the expense of about 400 dollars. A short distance below the last point, is a rapid of considerable extent, that will require a towing path, which may cost 220 dollars. At Wilson's point, opposite to the lower end of Baxter's Island, and 18¾ miles from St. Regis, runs another rapid, though of no great extent. The passage of vessels here will require a towing path of 250 yards in length; to construct this, and to remove a quantity of rocks lying along the point, will occasion an expense of about 350 dollars. At Point Hemlock, 19¾ miles from St. Regis, is a rapid

* This sketch, alluded to by colonel Hawkins, can be fully supplied, by reference to either Eddy's or Tanner's maps of the state of New-York.

that makes a towing path of about 100 yards in length necessary; this may cost 200 dollars. There is an obstruction in the navigation from Point Hemlock to Bluff Point, other than a steady ascent, whose average velocity is about two miles per hour. At the last mentioned Point we find rapids of considerable swiftness; but these are of inconsiderable length, and materials to form a path are at hand and plenty; its expense is estimated not to exceed 450 dollars. At several places between Bluff Point and Dry Island, (a distance of about eight miles,) the strength of the stream obliges the boatmen to have recourse to their setting poles; but in no place is it so swift as to make a pathway indispensably necessary. Dry Island itself, however, requires some notice: it is so called, because separated from the New-York main by a small stream, which in the summer season is nearly dry. It appears, indeed, that this passage between the inland and main was made several years ago. The bottom of this channel is composed of clay and round stones, mixed with gravel. A canal, sufficient for all the purposes of navigation, may be completed here at an expense of 1000 dollars. The next rapid that requires consideration is *Rapide plât*, running between an island of that name and the late village of Hamilton, (now called Waddington.) These falls are 37 miles above St. Regis. Judge Ogden, who resides upon the island, has erected a dam and bridge across them. It is said, previous to the erection of this dam, that this current was very impetuous for several miles, and that an abrupt fall of nearly 10 feet rendered the navigation utterly impracticable. The water having become comparatively smooth by means of the dam, Judge Ogden and others supposed that boats would be transported over his dam by means of a lock, and on petitioning the legislature of the state of New-York, obtained an act, dated 1st April, 1808, authorizing them to construct such a Canal and Locks as they should think proper to aid the navigation to this place. The grantees were authorized to receive a toll of 50 cents; and for every vessel under the burthen of two tons, and for every vessel exceeding six tons, one dollar and fifty cents. By this act the Canal and Locks were to be erected in three years from the first of July 1809, and were to be sufficiently large to afford free passage for boats of 50 feet in length, 10 feet in width, and drawing 2½ feet water. Intending to accomplish the object of this law, Judge Ogden has built a Lock 100 feet in length and 10½ feet lift. The walls are of stone, laid in the best cement, are 6 feet thick and 13 feet in height. The capacity of the lock is such as to admit a vessel of 75 feet hull, 13 feet beam, and drawing 3½ feet water. The plan is, in my opinion, judicious, and the work, as far as it has been accomplished, is well executed. The Lock above has cost about 12,000 dollars, and it is estimated that a dam built of stone will require 12,000 more, or, if built of stone and timber, 7000 dollars. The completion of these will constitute a lasting and easy passage for boats. The next rapid we meet is a *Point Iroquois*. The removal of a quantity of loose stones lying in the river at the extremity of this Point, and the construction of an ordinary towing path, of about 100 yards in length, would sufficiently facilitate navigation here. Five hundred and fifty dollars, judiciously expended, will complete this improvement.

About two miles above Point Iroquois, and at the head of Tousant's Island, is a rapid of about 400 yards in length, but of no great velocity. A pathway, that can be made for 200 dollars, will answer here.

Four miles above the last mentioned place commences the *Rapid au Galloupe*. This is generally known by the name of the Red mills, and is of great force for 250 yards. Although navigation may be rendered practicable here by means of a wide and strongly constructed towing path and railing, yet I could recommend the substitution of a Lock and Canal. A Lock of 5½ feet lift and a Canal 100 feet in length would be sufficient. But little excavation will here be necessary, and as stone and materials abound on or near the spot, it is believed that the expense of such a canal, with walls of stone laid in mortar, and the construction of a good Lock, would not exceed 10,000 dollars. A towing path alone, such as I have described, will cost about 1500 dollars.

At Tibbit's Point, near the Red mills, the current is such as to make a short pathway necessary. The expense of which may be estimated at 200 dollars.

There are no obstructions to a free and easy navigation from Tibbet's Point to Lake Ontario.

A recapitulation of the expenses of improving the navigation of St. Regis to Lake Ontario, by means of towing paths, including the Lock, Canal, and bridge at the *Rapide Plat*.

Towing path at Restoration Point - - - -	S	300 00
Do. Massena do. - - - - -		700 00
Point Ellicot - - - - - - - -		1,000 00
Sturgeon Point - - - - - - - -		5,500 00
Stone's Point - - - - - - - -		750 00
Pepper mill do. - - - - - - - -		400 00
Small Point below - - - - - - - -		200 00
Willson's Point - - - - - - - -		350 00
Point Hemlock - - - - - - - -		200 00
Bluff's Point - - - - - - - -		450 00
Dry Island - - - - - - - -		1,000 00
Luck, Dam, and Canal, at *Rapide Plat* - - - -		2,400 00
Towing path at Troquois - - - - - - -		550 00
Tousant Island - - - - - - - -		220 00
Rapide au Galloupe - - - - - - - -		1,500 00
Tibbet's Point - - - - - - - -		200 00
Add for clearing away trees that have fallen in the river, and removing other obstructions not noticed		5,000 00
For superintendance - - - - - - - -		3,000 00
3 per cent. for contingencies - - - - - -		2,245 00
		47,145 00
Should Locks be made at the Long Sault, and at the *Rapide au Galloupe*, the sum of 33,000 dollars must be added, being the difference of cost between Lockage and Towing paths. - -		33,000 00
Sum Total,	S	80,000 00

In the foregoing I have endeavoured to point out, with as much precision as my information would allow, the places where improvements are necessary, together with the expense at which they may be respectively effected; and although the estimates have been made with great care, it is probable that in some cases they are computed too high, in others too low: I feel pretty confident, however, that the above sum is sufficient to accomplish the object in view.

My remarks have hitherto been confined to the shores of the St. Lawrence; but, guided by the obvious intention of your letter, I deem it a duty to present another project for improving the navigation along the frontier; from the adoption of which most important benefits are anticipated.

From the mouth of Grass river* to a place called

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* Grass river rises in St. Lawrence county, New-York, and flows north-west about 50 miles, by comparative courses, and reaches within 4 miles from the Oswegatchie river, 12 miles above the mouth of the latter, into St. Lawrence, at the town of Ogden-

Fauchés Mills, is about 7 miles: for this distance, with the exception of a short and inconsiderable rapid 4 miles from its mouth, the river affords an excellent communication for vessels of 30 tons, those being the largest generally employed between Ogdensburgh and Montreal.

My design is to connect the St. Lawrence with Grass river, by opening a Canal from the Bay above Willson's Point to the foot of the rapid at Fauches Mills.

As there are no villages on the St. Lawrence to be accommodated, or in any way affected, by the Canal from Willson's Point to the mouth of Grass river, the shortest practicable route ought to be pursued. It is true, that art, combined with great labour and expense, may do much towards improving the navigation of these rapids. I scarcely believe it possible that all the difficulties opposing themselves to an easy passage can be entirely subdued; besides, any works erected upon them must be equally affected and endangered by the attrition of immense bodies of ice and water rushing against them.

The Canal can be supplied with water in abundance at the summit just above *Willson's Point*, and the arrangement and quality of the strata upon the above route are favourable for a Canal. There are no ranges of very high or very low lands; and there are no valleys, springs, brooks, or rivulets, (with one exception) worthy of notice that cross it. For a considerable portion of the distance the soil is composed of loam and clay, through which water cannot percolate: the soils of the residue, however, are porous, consisting of sand and gravel, but as the country here abounds with the best puddling stuff, (loom and coarse sand mixed) it is fair to presume that the expense will not be great. A short distance above Pepper Mill Point, the route is crossed by a bank upon an aqueduct.

It will be necessary to dig deep for a short distance at the proposed commencement of the Canal, unless it should be thought expedient to run it along the shore for about 900 yards below. This could be done with ease, the bank of the river at this place being composed of clay and loam. As the main river will always be preferred for a downward passage, it only becomes necessary to provide for ascending vessels. The projected Canal need not, therefore, be so wide as to admit large boats to pass each other. Twenty-five feet in width upon the surface of the water, 16 feet at the bottom, and 3½ feet water, will, it is believed, be sufficient.

It is the opinion of Mr. Adams, (our astronomical surveyor) that not more than 4 Locks, of 10 feet lift, would be required upon this route; and as the average length of these will not exceed 75 feet, the expense of Lockage may be safely computed at 32 000 dollars. The cost of this Canal would not vary much from the following estimate.

Expense for excavating, say 2¾ miles	$ 6,500 00
Grubbing, clearing away timber, puddling and towing paths	5,750 00
Wooden aqueduct over a brook at Grass river	30,500 00
4 Locks	32,000 00
Clearing out and deepening the channel at the small rapids in Grass river	500 00
Tools and implements	3,500 00
Engineer superintendance	4,000 00
Add for contingencies 5 per cent.	2,787 00
Aggregate,	58,537 00

The expenses of facilitating navigation along the shore of the St. Lawrence, from Massena Point, to Point Willson, (both included) by means of Locks and towing paths, amount, according to my estimate, to 34,000 dollars. Deduct this sum from that at which the Canal can be opened, and it presents a difference of 24,537. The advantages of the Canal navigation over that of the river, are too apparent to require elucidation.

Should the Canal project be adopted, the expenses of improving the navigation from St. Regis to Lake Ontario will stand thus:

Canal	$ 58,537 00
Towing path and Locks	46,145 00
	$104,682 00

Although I may already have incurred the charge of prolixity, yet I cannot conclude, without submitting a few remarks on the consequences likely to result from the improvement of navigation on this frontier.

The navigation of the St. Lawrence has hitherto been principally carried on upon the shore of Upper Canada, although no natural advantages contributed to secure this preference to our neighbours. The cause, however, is in the history of the country, for, until within a few years, the population of this frontier was exclusively British, and improvements in navigation were consequently confined to the Canada shore. But these are inconsiderable still, consisting chiefly of a few locks, wretchedly constructed, and of narrow and unsafe towing paths, which a little exertion on our part would consign to comparative disuse. Yet these improvements, however miserable they may be, (aided by the judicious policy of licensing our vessels and employing our sailors) have enabled the British government to maintain a decided superiority over us as carriers upon these waters. Indeed, it is not to be disguised, that nearly all exports and imports in that quarter are conveyed in British bottoms, or rather in vessels owned and navigated by Americans, sailing under British colours. But render the communication on our side safe and commodious, and these now increasing evils will vanish. Afford our own people facilities of intercourse with one another and with Canada, and you will open a wide field for speculation and adventure, you will then impart another spring to commerce, and new life to agriculture.

An easy exportation of our surplus commodities must excite industry, and open a true source of wealth. By these two, you will hold an irresistible inducement to settlers, and speedily require an industrious and enterprising frontier population. Such a population would, in the event of another war, prove more invincible than all the garrisons we have ever had upon it, and the balance of trade there falling greatly in our favour. This line of defence would constantly gain strength at the expense of the enemy.

It will not be forgotten, that this river runs into a foreign country, by the laws of which, its great water communication may be disadvantageously obstructed, or our commerce upon it subjected to indiscriminate restriction.

To guard against these, let government place itself in a situation to retaliate, let us improve our local advantages, and provide communication within our own limits shorter and better than the colonists can ever have within theirs, and upon and through which, it will be their interest to conduct their trading, and I question not but we shall secure a lasting and highly beneficial commerce with them.

The proposed improvements will, in their completion,

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burg. Where the two rivers approach the nearest to each other, they are united by a natural canal. Below this very remarkable connexion the Grass river flows 40 miles, gradually approaching the St. Lawrence, into which it finally falls, 5 miles above St. Regis.

not only secure a growing augmentation of the public receipts, but add facility and certainty to their collection; and numbers of well informed men, residing upon this frontier, have discovered that the mere increase of revenue, added to tollage of the locks, &c. will fully reimburse the above expense, in less than a period of ten years.

It is also believed, that the practice of smuggling, too frequently sheltered in this quarter, under the protection and for the benefit of distinguished individuals, a practice no less immoral in principle than ruinous to the treasury, will be in a great measure restrained, if not wholly prevented, by these improvements. I forbear to dilate upon their importance in other respects; such as the facility they will impart to warlike operations; the immense sums they will consequently save; the ready communications they will supply for commerce, and thus, by rendering intercourse more easy, will more intimately bind our citizens together. These it is only necessary to mention—they are too plain to need illustration, though too important to be overlooked.

I have the honour to be, &c.

The foregoing communication is alike honorable to the intelligence and patriotic feelings of its author, but in his estimate of expense he has, no doubt, been much too limited. The series of rapids, from Ogdensburg to St. Regis, is very correctly delineated. The causes which have hitherto carried the navigation to the Canada shore of St. Lawrence were, as Col. Hawkins states, in great part political, but the mere circumstance of the uncultivated condition of the United States shore has had a large share in producing this result.

If five times the sum estimated by Col. Hawkins was expended upon this inland navigable line, it would be money most beneficially employed.

Below the limit of the United States, the St. Lawrence expands into lake St. Francis, of about 30 miles in length, with a mean width of 4 miles. At the lower end of this lake the river again contracts into two narrow channels, separated by Gros Isle. Here rapids again occur, which is also the case at the Cedars, a few miles lower down. At the lower end of the Cedar rapids, the river again dilates, having one channel communicating with the Ottawa river, and the other opening into lake St. Louis. The latter continues 17 miles to La Chine, the upper port of Montreal. Here the river is once more restricted to a confined channel, with strong rapids. Nearly opposite to Montreal, however, the last rapids occur, and below that point to lake St. Peters, or head of tide water, the current is gentle, and channel sufficiently deep for 600 ton vessels.

The observations upon the St. Lawrence basin might be indefinitely enlarged, but we must close our general view of that subject with a few brief notices.

Ottawa, or Grand river, is a great northern branch of St. Lawrence, rising in the imperfectly known regions north from lake Huron, and flowing south-east, by comparative courses, 600 miles, falls into the Coteau du Lac, 25 miles nearly west from the city of Montreal. The Ottawa, often called the Grand river, is one of the routes pursued by the Canadian traders, who ascend that river, and, by a short portage, enter lake Nipissing, and from the latter into lake Huron. The distance from Montreal into lake Superior is one-third longer through the St. Lawrence and great lakes, than by the Ottawa river. The navigation of the latter is much incumbered with rapids and shoals, but is, nevertheless, much frequented, from its superior safety, and from being so much shorter.

Montreal is extremely well situated to become the centre of a very extensive inland commerce. It is already such, as far as the advance of population will admit. Standing at the head of ship navigation, this city is, on the St. Lawrence, the point of contact between the foreign and interior commerce of an immense expanse of country.

La Chine (Bouchette, 135,) is the upper port of Montreal, and situated on the same island with that city, and at the lower extremity of lake St. Louis. La Chine is the centre of shipment between the Upper and Lower provinces, and the North country. In May and November, boats, to and from various parts of Upper Canada, are continually arriving and departing from this place. They are from 35 to 40 feet in length, with about 6 feet beam; their usual freight from 4 to 4½ tons. They are worked by oars, a mast, and sail, drag-ropes for towing, and long poles for setting them through the strong currents or rapids. Four men manage them in summer. They bring down wheat, flour, salt provisions, pot and pearl ashes, and peltries. They are usually navigated in squadrons of from 4 to 15 boats, in order to enable the crews to aid each other in passing the rapids.

From La Chine, (Bouchette, 136,) the bark canoes employed by the North-West company in the fur trade take their departure. Of all the contrivances for transporting heavy burdens by water, these vessels are perhaps the most extraordinary. They are formed by a slight frame, to which the bark of the white birch tree, (Betula alba) in slips, is attached. These canoes are the lightest of all navigable vessels to their capacity. It is the latter circumstance which enables the Canadian boatmen to perform so many long and fatiguing portages, with their vessels and cargo.

With these light canoes the traders proceed up the Grand, or Ottawa river, to the south-west branch, by which, and a chain of small lakes, they reach Nipissing; through it, and down the French river, into lake Huron; along its northern coast, up the narrows of St. Mercy, into lake Superior; and then, by its northern side, to the Grand Portage, a distance of about 11,000 from the place of their departure. From the Grand Portage, which is 9 miles across, there is a continuation of similar toils in bark canoes of smaller size, through chains of lakes and streams, that run from the height of land westward to the lake of the Woods, and lake Winnepeg, to the more distant establishments of the company in the remote regions of the north-west country.

From the city of Montreal to the eastward, the shores are from 15 to 20 feet above the level of the St. Lawrence; but, in the opposite direction, towards La Chine, they are low. Between the Coteau St. Pierre and the river, the land is so flat, and particularly near the small lake St. Pierre so marshy, as to induce a conjecture that it was once covered with water. Over this place it is intended to cut a canal, by which a direct communication would be formed between La Chine and the city, and the rapid of St. Louis (intervening) avoided.*

Near the head of lake St. Louis extends the Point des Cascades, and in the river lies the island des Cascades, which, with one or two other smaller ones, break the current of the river at its entrance into lake St. Louis, and present nearly the same effect that would be produced by the most violent tempest. To avoid these, a canal, usually called the Military Canal, has been constructed across the point of land, and through which the boats pass to the locks at Le Buiessen; it is 500 yards in length. At a place near Lorguil's mill, the boats going up the St. Lawrence are unloaded, and their freights transported in carts to the village, while the empty boats are towed through the rapid du Coteau des Coches. At Coteau du Cac, just above the river de Lisle, ascending boats again enter locks, to avoid a very strong rapid.

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* *Montreal, April 3d,* 1822.—We are informed that the contractors for the *Lachine Canal* have employed from 2 to 300 men all the winter, and will immediately add 500 more to their number, and prosecute their undertaking with all possible energy.

We may now take a brief view of those rivers by which a water communication is had from the United States to the St. Lawrence. Of these, the most important is the river Richelieu, which flows from the lake Champlain, in a northerly course, and unites with the river St. Lawrence, at the town of William Henry. The navigation is carried on by boats, canoes, and rafts, (Bouchette, p. 224.) From its junction with the St. Lawrence, decked vessels of 150 tons may ascend 12 or 14 miles; its mouth is about 250 yards in width, and this continues nearly to the basin of Chambly; from thence to the Island du Portage, it is 500 yards; beyond this, it is double that extent to St. John's, from whence there is a ship navigation 160 miles along lake Champlain. From the basin down to the St. Lawrence, the current is gentle, notwithstanding the shoals and flats; but, from lake Champlain, the stream is in some places broken by rapids. There is much trade upon this important navigation, and its importance is unequivocal.

The river St. Francis is also an important line of communication, only it is obstructed by a number of violent rapids; its source is a large lake of the same name, in the townships of Garthley and Coleraine; it flows in a south-west direction for 30 miles, then nearly north-west for about 80 miles, and falls into the lake of St. Peter; a branch connects with lake Memphremagog, from which several streams descend into the state of Vermont. Notwithstanding the imperfection of this navigation, much trade is thereby sent to the St. Lawrence.

The general staples brought down the St. Lawrence, are peltry, grain, flour, and timber. The town of Ogdensburg, at the mouth of the Oswegatchie, in St. Lawrence county, New-York, is the point of contact between ship and boat navigation above the rapids. From Ogdensburg the navigation is pursued up the St. Lawrence, and through lake Ontario, in sloops and large vessels, 170 miles to the river Niagara, where, on account of the great falls, a trans-shipment and land-carriage takes place, in order to reach lake Erie. Canals have been proposed, both on the British and American side, to pass the falls. At present, on the British side, the goods are landed at Queenstown, seven miles within the Niagara river, from whence they are transported by waggons to the Chippewa creek. Down this river they are sent into the lake Erie, (231 miles in length,) which is navigated by vessels of 60 or 70 tons, that pass through the straits of Detroit, (28 miles long) and the lake of St. Clair, (20 miles across) and along the river St. Clair, (60 miles in length) into the lakes Huron and Michigan. In lake St. Clair the water is so shallow, that the vessels must be lightened. Between lake Huron and lake Superior, are the rapids of St. Mary straits, along a part of which a canal has been formed by the North West company.

The river St. Lawrence, from Quebec to Kingston, and a great part of the lakes, are frozen over from the beginning of December until the month of April, and during that period navigation, of course, ceases, but sledges are passed upon the ice.

We have now completed a brief survey of the basins of inland navigation in the United States, and proceed to notice the canals and locks already completed, now in progress, or which are designed, with a prospect of being carried into effect.

In the latter review, our advance will be made in a retrogade direction from that pursued when examining the rivers.

The improvements made upon the navigation of the Connecticut river, within the limits of New-Hampshire, are the most northern works of a similar nature yet made in the United States. A canal with locks has been made round the falls near Hanover, opposite Norwich, in Vermont, at North Lat. 43° 41′. This is about 10 minutes of latitude north of Whitehall, in New-York, the northern extremity of the canal between the Hudson river and lake Champlain. In several other places from Hanover, in New-Hampshire, to Springfield, in Massachusetts, canals and locks have been constructed. The distance to which an uninterrupted navigation has been effected in the Connecticut river, by the aid of canals and locks, is upwards of 150 miles, following the windings of the stream. Below Springfield, the river was navigable, for boats of considerable tonnage, in its natural state.

The most remarkable canals on Connecticut river, in Massachusetts, is at South Hadley. The upper falls are 55 feet descent. The lower, or Willimansett fall, descends 18 feet. A canal leads round each fall. These canals belong to separate companies; the expenditure about 200,000 dollars. By the improvements made at Hadley and Springfield, the most fertile part of Massachusetts and New-Hampshire are opened to the Atlantic Ocean.

The great canal operations of Massachusetts have, however, been performed upon the Merrimac, and between that stream and Boston harbour. The geographical structure of the country near Boston demands some notice, previous to an investigation of the canals and locks already made in that quarter.

The Merrimac river rises in the mountains of New-Hampshire, but is more particularly supplied with water from the Winnipiseogee lake, Contoocook river, Nashua river, and Concord river. The general course of the Merrimac is south south-east, as far as about midway between the mouths of the Nashua and Concord branches. Here it turns to north-east, which course is maintained to Newburyport, where the river is lost in the Atlantic Ocean. The course of the Merrimac, below its junction with the Concord branch, is very nearly parallel to that of the Atlantic coast, from the mouth of Charles river, in Boston harbour, to Cape Ann, leaving an intervening peninsula of 30 miles in length, from north-east to south-west, and 18 miles wide.

In order to avoid the great circuit from the Patucket falls above Chelmsford, by the Merrimac river and Atlantic Ocean, a canal was projected and executed across the peninsula.

In the higher part of its course, the Concord is a sluggish stream, but is precipitated over falls in the town of Belerica, 4 miles above its confluence with the Merrimac. Advantage was taken of the superior height of the water in Concord river above its falls. The canal commences in the Merrimac river above the Patucket falls, and in a distance 3¾ miles by course of south-east, and by three locks descends 21 feet to the water level in Concord river above the falls. It crosses Concord river, and follows the level of that stream 11 miles. In this latter distance, much deep cutting was unavoidable, and in some places to the depth of 20 feet, and through some large ledges of rocks. Beside several smaller, two fine aqueducts were constructed; one of 280 feet broad, 22 feet high over the Shawshine river, and one of less dimension at Medford. At the end of the 11 miles from Concord is a lock of 7 feet lift and fall, and another of equal dimensions 1½ mile nearer Boston.

The whole length of the Middlesex canal is 29¾ miles, and entire fall 107 feet by 13 locks. The canal is 24 feet, and with a depth of 4 feet water. The locks are 90 feet by 12, of excellent masonry.

Another canal has been also cut around Patucket falls, in order to connect that part of Merrimac river above those obstructions with that below to tide water. The latter canal is 4 miles in length, and by 3 locks descends 34 feet. It does not extend to tide water, but the stream below the mouth of the canal, though rapid, is navigable, and falling in about 36 miles, 45 feet reaches the tide at Haverhill.

The Merrimac, above Patucket falls, has been rendered navigable to Concord. The first great improvement made in the stream below the latter place is the Bow canal constructed in 1812, at an expense of 20,000 dollars. Hooksett canal, 6 miles still lower, in a fall of 17 feet, passes another difficult fall or rapid. Amoskeag canal, 8 miles below that of Hooksett, affords the second most extensive body of works of a similar nature in New-England. In nine miles below Amoskeag canal are 6 more of smaller extent, round as many falls. Cromwell's falls, also made navigable by a canal, is 14 miles below Amoskeag, and 15 miles still lower is the Wicasse falls, around which is also a canal. This is the last canal above that of Middlesex.

The following communication, from Mr. John L. Sullivan to the President of the Board of Commissioners of the grand canal, New-York, gives every requisite information respecting the canal improvements in Massachusetts and New-Hampshire, or the Merrimac. That part of Mr. Sullivan's letter relating to the New-York canals is omitted in this place, as irrelevant to the subject before us.

Copy of part of a letter to the President of the Board of Commissioners, from John L. Sullivan, Esquire, who has had the charge of constructing several short canals, with locks, dams, &c. around falls, in the Merrimac river, and has for eight years been superintendant of the Middlesex canal, in Massachusetts.

Albany, March 7, 1817.

The Hon. De Witt Clinton,
President of the Board of Canal Commissioners.
Sir,

The Middlesex canal is 27 miles in length; its depth is intended to carry at least 3 feet of water. The banks, where formed, are meant to be one foot above the water.

The width generally 30 feet on the surface, and on the bottom 20 feet. In carrying the work on it was found necessary to purchase some estates, the whole of which was not essential to the canal. The lands were generally paid for, where most valuable. There was some considerable expense attending litigations, and perhaps some mistakes, which are not likely to happen in the proposed work. The whole expense in assessments has been 520,000 dollars; not including the application of income for several years past, in renovating and completing it; and the buildings, wharves, &c. necessary to the business. As neither of these objects of expenditure apply to the present question, I shall leave them out, and also deduct 50,000 dollars, as having been applied to the other works leading to the principal canal.

Analysis of the cost of Middlesex Canal, in the state of Massachusetts.

Description of the Levels.	Embankment.	Excavations.	Locks.	Aqueducts	Culverts.	Bridges.	Lands & Extras.
1st. in Charlestown.							
The mills and contiguous land—reserving the part used for the landing, ...							10,000
1st Lock in the tide, ...			7000				
2 Lock in the tide, ...			3000				
Digging the first level about 600 feet in length, say		1000					
3d Lock. (All the Locks except those at Chelmsford, consist of walls to sustain the banks of the Lock pit, containing 300 perches. } in length 100 feet, height 12, thickness 3. . . . . . In most instances the stone were brought from a distance. The frame of the Locks were of yellow pine, then considered as durable as white oak; and as expensive. The gates were of oak. The length of the wood work about 100 feet. The width 11 feet at top and 10 at bottom. The lift generally 8 feet. . .			5000				
2d Level.							
To 1 mile through valuable clay land, containing about 10 acres, at 500							5000
2d mile, ... 300							6000
		1000	15,000				21,000

Analysis of the cost of Middlesex Canal, in the state of Massachusetts.—Continued.

Description of the Levels.	Embankment.	Excavations.	Locks.	Aqueducts	Culverts.	Bridges.	Lands & Extras.
		1000	15,000				21,000
3d mile, 300							2000
4th mile, 200							
Where the excavation is of the ordinary depth of four feet, I will assume the contents to be 30,000 cubic yards, 1st 2 miles, I estimate the excavation at 20 cts.		12.000					
Extra excavation for basins, 15,000 yards, at 25 cents.							3750
2 miles of embankment of 50 cents, including the excavation of some stone,	30,000						
4 Culverts.					400		
10 Bridges.						3000	
1 Aqueduct, 110 feet in length, surface of water 10 feet above the tide, standing on 3 piers, 2 abutments.							
Height of them 12 feet,							
20 feet length,							
average 6 feet thick.				3000			
300 perch at 3 dollars, the stone being brought from some distance.							
Materials, pine.							
Carpentry.							
Piling the ends, labour, &c.							
1st 4 miles, 1st and 2d levels,	30,000	13,000	15,000	3000	400	3000	26,750
3d Level.							
1 Lock			3000				
2 miles, at 20 cents, (easy)		12,000					
1 mile at 40 cts. deep, (easy)		12,000					
30 acres at 100 dollars,							3000
1 Culvert,					100		
1 aqueduct, twice as large as the former,				6000			
1st seven miles.	30,000	37,000	18,000	9000	500	3000	29,750
4th Level, 3½ Miles.							
3 Locks,			9000				
2 miles at 20 cts.		12,000					
½ mile at 60 cts. 25 feet deep part of the way,		9,000					
3 culverts and 2 waste-ways,					600		
Land 30 acres at 50 dollars,							15,000
2 Bridges,						500	
1st 10 Miles,	30,000	58,000	27,000	9000	1100	3500	31,250
5th Level, 6 Miles.							
3 miles at 20 cts.		18,000					
1 mile at 60 cts.		18,000					
2 miles of bank, average 40	24,000						
7 culverts and waste-ways,					1000		
1 Aqueduct,				2000			
Land,							1800
Extra excavation of rock,							1000
Bridges,						3300	
1st 16 miles,	54,000	97,000	27,000	11,000	2100	6800	34,050
6th Level, 2 Miles.							
Excavation, 1 mile,		6,000					
Embankment, 1 mile, 60 cts.	18,000						
1 Lock,			3000				
4 Bridges,						1200	
1 small Aqueduct,				2000			
20 acres, at 30 dollars,							600
1st 18 miles,	72,000	103000	30,000	13,000	2100	8000	34,650

Analysis of the cost of Middlesex Canal, in the state of Massachusetts.—Continued.

Description of the Levels.	Embankment.	Excavations.	Locks.	Aqueducts	Culverts.	Bridges.	Lands & Extras.
	72,000	103000	30,000	13,000	2100	8000	34,650
7th Level. 5 Miles.							
3 miles excavation, 20		18,000					
2 miles embankment, 40	24,000						
1 Aqueduct, ...				10,000			
1 Lock, ...			3000				
6 Bridges, ...						1800	
8 Culverts, ...					800		
Land, 50 acres at 15 dollars, . . .							750
Excavation of rock, say 3000 perch, at 5 dollars,							15,000
1 Guard Lock therein, ...			1000				
1st 22 miles canal, including the tide work at Charlestown	96,000	121000	34,000	23,000	2900	9800	50,400
Concord River.							
First purchase of mill site, . . .							10,000
Improvement, ...							10,000
Dam, ...							1,000
8th Level, 5 Miles.							
1 Guard Lock, excavated in the Ledge; (cost uncertain) no wood work but the gates, say . .			5000				
3 miles at 20 cents, ...		18,000					
2 miles embankment, at 40	24,000						
2 Aqueducts, ...				10,000			
6 Culverts, ...					600		
6 Bridges, ...						1800	
3 Stone Locks, ...			15,000				
Excavation of the basin, ...							1000
Purchase of land and erection of Stores, . .							3000
27 Miles, ...	120000	139000	54,000	33,000	3500	11,600	75,400

Summary of the different divisions of expenditure on the Middlesex Canal.

Lands and extraordinary purchases, and excavation of rock—	$75,400
Bridges, (some of them less expensive)	11,600
Culverts,	3,500
Aqueducts,	33,000
Locks,	54.000
Excavation,	139,000
Embankments,	120,000
	448,000
Contingencies,	22,000
	470,000

To reduce this comparison to the par of the most favourable representation of the proposed canal, the following deductions should be made—

Lands and extras,		$75.400
$\frac{2}{3}$ the bridges,		7,000
And as the proportion of Locks is as 1 to 5, so $\frac{1}{5}$ would be	$11,000	
To which add for superior size and quality,	10,000	
	21,000	
Leaving of this item to be deducted		33,000
		115,000
and $\frac{2}{3}$ the embankments		80,000
In all		$195,000

Which deducted from 470,000, leaves	275,000
Amount brought over, being cost of Middlesex canal divested of its peculiarities, equal to $10,500 per mile,	275,000
At this rate, the New-York state canal would cost for the 353 miles, at $10,500 per mile, or	3,706,500
Allowance for increased size of the trunk being as 7 to 4—supposing $\frac{1}{20}$ the ditance to be embankment; leaving 330 miles, at $2,812 additional, is	927,960
	$4,634.460

In this there is no estimate of superior workmanship and materials in the aqueducts.

If, however, it were presumed that the route might be full as difficult as that of the Middlesex, the estimate would stand thus:

If 27 miles cost 470,000 dollars, 353 miles would cost	$6.500.000
To which add for increase of size and depth as above,	927,960
	$7.427.960

And to this is to be added the superiority of work.

But, it being conceded that the ground is on the whole more favourable, this may be too high; especially as the Middlesex was not excavated by machines; but labour at that time was low. Common men had from 8 to 10 dollars per month.

The works to extend the navigation from the junction of the canal with the Merrimac, up that river to Concord, New-Hampshire, cost as follows, viz.

Wicasee lock and canal. thus described.—A rapid for half a mile between an island and the western shore, is crossed with a dam of stone and timber, 200 yards: this raises the water above, about a foot which saved digging on the other side of the island, where the lock is placed. This side afforded a passage for high water, six rods wide. From the lock to its entrance is 1900 feet. This space was encumbered with masses of rock of every size, and with earth, estimated at 4000 square yards. The lock is placed in the middle of the stream; its side walls are one hundred feet in length, connected with the shore by wing-walls, each about fifty feet. The wing walls are faced with plank driven into the bottom and extended into the shores. The walls, having no support, were necessarily thick, to sustain the pressure of the lock and the shock of the freshets. They are 12 feet high, and average 8 feet thick; containing 1200 perch. The stone was split out large, and drawn $\frac{1}{2}$ a mile, loaded for the most part on to a boat with a crane and windlass, and thence laid. The foundation was difficult, the bottom was encumbered with stones, the water from 2 to 7 feet deep, and not being clear, the work of deepening, filling up, and laying the walls under water, was done by feeling, diving, &c.

The whole expense including quantities of powder, much iron, boats, utensils, barracks, bedding, and the dam, was 14,000 dollars.

The labour was performed by about 100 men, between the middle of July and November.

Cromwell's lock is similar, with 120 rods of dam extending to the head of the rapid. It contains about 600 perch of stone, brought from the distance of a mile.

Whole expense about - -	$9,000
Moors' falls has two locks, with 200 rods of dam. Here was much excavation of earth and removal of stone, - -	15,000
Coos, a similar lock with less dam, -	5,000
Goff's Lock, - - - -	7,000
Short falls, - - - - -	6,000
Griffin's, - - - - -	4.000
Merril's falls Lock, - - -	10.000

All these walls were of split stone, difficult to be got on, and much iron was used.

Amoskeig canal is the greatest work of the kind on this navigation. The fall around which it is carried is one mile in length, and the perpendicular measurement 45 feet: 2000 feet are excavated; the rest of stone and dams. The whole expense is uncertain, but the part which was rebuilt the last season may serve the purpose of comparison in some measure, viz. three locks connected together, each 100 feet in length, from 10 to 11 feet wide, lift each 8 feet. The walls of one side without embankment, the other with. The contents of these walls being 8 feet average outside, and 5 feet average inside—is $6\frac{1}{2}$, say 7 feet thick, and 12 feet high, will be 2000 perch.

The old work was first removed; the old locks were supported by wooden ties above; few of the stone answered anew.

The stone were split, carted half a mile, loaded on to boats, brought down six miles, unloaded on a platform, loaded on to trucks, brought three hundred feet to the locks, unloaded on a stage, then worked into the walls.

The drought of last season impeded the boating considerably. The locks are of white oak timber, and white pine planks, the whole of the best workmanship of the kind.

The expense, including wages, boarding, spirits, implements, and materials, was little more than $10,000.

Hooksetld Canal consists of two locks, two basins, and a guard gate and stone dam. The stone was got out and boated over the river. There was considerable excavation, (including the purchase of a mill-seat.) The whole expense has been 15,000 dollars.

Bow Canal is a work of uncommon difficulty and variety. The perpendicular fall is 25 feet. Near its upper entrance, a dam is thrown across the river, which is here 200 yards wide. The guard gates are supported by stone abutments, 14 feet high. One half of the first 300 feet was ledge, 6 feet deep, and 20 feet wide, say 1400 perch.

The next 300 feet was made by an embankment supported by a wall 12 feet high, 7 feet at bottom, and 4 at top, standing in the river, containing about 800 perch.

The next 250 feet is carried through a hill or ledge of rock, of a slaty kind, but hard enough to be blasted, 12 feet wide and 16 deep, containing about 2000 perch of excavation, 1900 yards.

The next 300 feet is excavated in gravel, on the slope of a hill, sustained on one side by a wall 8 feet high, 4 at bottom and 2 at top, battering back more than usual.

Then come the three locks, each 90 feet in length, containing about 2000 perch. The lower lock is set 4 feet below the low water mark. It was necessary to keep the pit clear by bailing and pumping. From the locks a low water channel was made. The stone were drawn from a quarter to half a mile, after being split. This work, including the purchase of five acres of land, cost 21,000 dollars.

These canals give a net income of 6, 7, 8 per cent. and are increasing fast in productiveness.

The Middlesex gave 32,000 dollars, or about 3 per cent. net income.

The following general observations may not be unacceptable to the board.

It is found to have been bad economy on the Middlesex canal, to have constructed any thing of perishable materials. Had all the locks been laid in cement, and constructed in the best manner, the property would have yielded dividends of income, and sustained its prospective value to a higher degree than at present.

The canal will be interrupted for three weeks, the ensuing summer, to put up a new aqueduct over Shawshine river. Other similar interruptions may be expected, whenever the other aqueducts and locks must be rebuilt. If the winter season is taken for the work, it will be more difficult and more expensive.

Probably for 50 per cent. additional for the aqueducts, they may be made of iron. Were it double, I should still deem it the best economy.

If this communication, which is very hasty and imperfect, can be of any use to the board, I shall have much pleasure in the reflection of having contributed, in any degree, to the great object of their attention.

With the highest respect,
I am, Sir, your most obed't. serv't,
John L. Sullivan.

The subjoined extract contains much very valuable and minute matter respecting the Middlesex canal, omitted in Mr. Sullivan's report. It is here inserted, as illustrative of the advance of canal improvement and science in the United States.

"The following information, respecting the Middlesex canal, was obtained in May last, by two of the commissioners (of the New-York canals) who visited, and carefully examined that canal, throughout its whole extent, and committed to writing, on the spot, the result of their own observations, as well as the answers to all their enquiries, which were obligingly given, by the very intelligent agent (Mr. Sullivan) of the canal company.

The canal is 27 miles long, and connects the tide-water, in Boston harbour at Charlestown, with the Merrimac river. The water in the canal is 30 feet wide at its surface, 20 feet at its bottom, and 3 feet deep. The Concord or Sudbury river crosses the line of the canal on the summit-level, 22 miles from Charlestown, and 5 miles from the junction of the canal with the Merrimac, and wholly supplies it with water for locking down each way from the summit-level. From tide-water to the summit-level is an ascent of 104 feet, and from thence to the Merrimac a descent of 32 feet. There are, in all, 20 locks of different lifts, of which the highest is 12 feet. These locks are 75 feet long in the clear, 10 feet wide at the bottom, and 11 feet at the top.

Boats for the transportation of merchandise and produce carry 14 tons, and are drawn by one horse 3 miles an hour. Packet-boats pass the whole length in 5 hours coming down, and 7 hours going up. To each boat there are three men; two, however, are sufficient to manage the boat on the canal, the other being wanted only on the Merrimac river. From the summit-level down the canal there is a current, which exceeds in no place half a mile per hour, there being a fall or descent in the canal of one inch per mile. The expense of transporting a ton the whole length of the canal is $3 50, of which sum $1 70 is toll, and $1 80 is freight.

Across the canal there are 50 bridges made by the canal company; they consist of 2 stone abutments (one on each side of the canal) 20 feet apart: from one of these abutments to the other, are laid sills or string-pieces of wood covered with plank, and of sufficient height for the towing horses to pass under. The towing path under the bridges occupies 6 or 7 feet.

Two miles from the lower end of the canal, Mystick river, a turnpike road, and the canal, run a little distance parallel with each other, the road being between the canal and river. Here is afforded a good opportunity of comparing the relative advantages of these three modes of conveyance.

Heavier boats than those above-mentioned are used on the canal for transporting fire-wood, lumber, &c.; they are shaped like a scow, are 75 feet long, 9 1-2 feet wide, and carry 25 tons of wood.

The towing-path is generally 8 feet wide, so that horses and oxen may easily pass each other. On the opposite side of the canal, where a towing-path is not wanted, the upper surface of the bank or embankment is five feet wide, and this is found to be sufficient. A branch-canal, or side-cut, is made to connect the main canal with Mystick river near Medford; this is owned by a separate company, and is principally used for transporting timber to Medford for ship-building.

The canal company was incorporated in 1789, and the next year commenced the work of making the canal.—When the canal was begun, the price of labour by the month was $8. The canal was opened for use in 1804, though not completed in 1808, when Mr. Sullivan took charge of it. Some repairs and new constructions have been made every year since. In assessments upon the proprietors, there has been laid out on the canal $528,000, and about $50,000 more, derived from tolls, has been expended in buildings, wharves, &c. At Medford is a swivel bridge, which is found to be very inconvenient. The principal articles transported on the canal are wood, timber, lumber of all kinds, pot and pearl ashes, rye, oats, provisions, and building stone from the Merrimac to Boston. Last year 12,000 cords of wood were transported down the canal, and there are more tons of timber in rafts brought down, than of wood.

More than one half of the whole length of the canal is more or less embanked, or raised above the natural surface of the ground. Above Medford is an aqueduct across the Mystick river, of which the abutments are 100 feet apart, and between them are three stone piers, each 8 feet thick, for supporting the aqueduct. The tide flows up the Mystick river above this place. The surface of the water in the aqueduct is 10 feet above the surface of the water in the river below, at high water. This aqueduct consists of a kind of trough made of timber and plank, which has stood 16 years, but is beginning to decay. The timber is framed together in the usual way of carpenter's work, by tenants and mortises, and strengthened by braces. As tenants soon rot and give way, it might have been made on a better and more durable construction with knees and bolts in the manner of ship-building. At the upper end of the aqueduct is a lock of 12 feet lift.

Mr. Weston, an English engineer, took the levels of the whole length of the line of this canal, part of the way on two routes. He estimated the expense of making it at 100.000*l.* sterling. The company went on to make the canal without any further aid from any European engineer, and found Mr. Weston's levels to be correct.

Over Syms' river is an aqueduct, of which the abutments are 120 feet apart, with three intervening piers. The water in the aqueduct is 30 feet higher than the water in the stream below. These aqueducts all afford convenient waste-weirs. When the water is not drawn off from the canal at the commencement of winter, the expansion of its freezing spreads, and injures the timbers of the aqueducts; wherefore it is the practice, just before the winter sets in, to draw off about one-third of the water.

Half a mile above the last mentioned aqueduct is deep cutting, 40 rods in length, through loose sand and gravel. In the deepest part of the excavation is 20 feet below the natural surface of the earth; and the part excavated is here, from 90 to 100 feet in width at the top. The earth was chiefly carried away in wheel-barrows, some in carts, to an embankment just above, on the right side. Half a mile higher up the earth is very porous, and on the right side the water leaks out through or under an embankment: this might have been prevented, by putting 2 or 3 feet of water-tight stuff in the bottom of the canal.

Near this place are two water-gates, by which the water of the canal is drawn off in the spring for the purpose of clearing out the earth, stones, &c. which fall into it and injure the navigation. The expense of this is perhaps $500 a year.

Mr. Sullivan states that he has had a steam-boat on the Merrimac river for the purpose of towing boats; he found that a man by a rope could easily hold a boat in tow immediately astern of the steam-boat, which it would require a horse, on the bank of the river, to tow with the same velocity: such, in his opinion, is the great diminution of the resistance of the water to the head of a boat which is drawn in the wake of another boat.

For some weeks in the spring the canal leaks much more than it does the remainder of the season; this is because the banks had been recently swelled and loosened by the action of the frost. Three men, with a horse and boat, are, in the summer, constantly employed to keep the banks, and particularly the towing-path, in order.

The lands within six miles of the canal, on each side, have increased one-third in price; while land in the country generally retains its former value. In the state of New-Hampshire, through which the Merrimac flows, timber is now worth from 1 to 3 dollars per ton standing; before the canal was made it was worth nothing; so that in the article of timber alone, that state is supposed to have been benefited to the amount of at least 5,000,000 of dollars. The wood-land there has risen in price, since the opening of the canal, from $2 per acre to $6, $8, and $10 per acre.

In Woburn, a pretty high embankment, which was made in the winter, across a marsh, sunk down in the spring at the breaking up of the frost, so that its top was just level with the natural earth: another embankment was then raised upon it. Near this place the canal, by a deep-cutting of 25 feet, passes through a hill. An embankment at Maple meadow, in the town of Wilmington, is near 80 rods long, and 25 feet high to the top of the towing-path. At a place called the Sinking meadow, in the above named town, an embankment is made across a marsh, of about 30 rods in extent. When this embankment was commenced, it was found that the dirt and stuff carried on to form the embankment kept gradually sinking into the marsh; when measures were taken to ascertain how much it would sink; the labourers continued to carry on stuff, which gradually went down until the whole embankment sunk to the depth of 60 feet! The great expense of making this embankment across the marsh might have been foreseen and prevented. The depth and softness of the marsh might have been ascertained by sounding it with an iron rod, and by conducting the canal circuitously around its margin, a solid foundation might have been secured.

By the act of incorporation, the legislature authorized the company to occupy 5 rods of land in width on one side of the centre of the canal, and 3 rods on the other. If the owners of the land did not apply for pay within a year, it was deemed a donation. In the statement of monies expended, before made, are included the costs of several law-suits, the building of boats, of offices, the purchase of 70 acres of land, and the erection of mills at Billerica. The land and mills cost $10,000. There is no income derived from hiring out water privileges for hydraulic operations. The canal receives its whole supply of water from the Concord river; and if any were let out for hydraulic purposes, a current would be created, the inconveniences of which would probably more than counterbalance all the advantages of income.

Either through design or accident, logs, stumps, and sticks, were in some places left in the banks when the canal was made; and these, having now become rotten, leave unsound places, through which the water escapes. A great part of the canal was made by contractors in small parts or jobs, and where two jobs of embankment met each other, the workmen did not, in some cases, take the precaution to prevent the stones, as they threw on the stuff, from rolling down together from each end of the separate job, and thereby forming a loose, porous, and leaky place in the embankment.

The aqueduct over the Shawshine river is, between the abutments, 140 feet. The water in it is 35 feet higher than the surface of the river below. This aqueduct has been made 20 years; it is, like the other aqueducts on this canal, made of wood, and is so much decayed as to require temporary props to support it.— There are three piers between the abutments, and, between the outside pier and the abutment on each side, there is a kind of wooden pier. On the inside or river side of both the abutments, and on both sides of the piers, at suitable distances, large horizontal timbers are embedded, which serve to support the lower ends of the aqueduct braces: when these timbers become rotten, the stone work will probably fall down. From each end of this aqueduct, to the distance of 500 feet, is an embankment nearly 35 feet high.

During the war, the timber used to repair the Constitution frigate was brought down the canal to Boston, and that used to build the Independence seventy-four, except the live oak, was procured through the same channel, as also were many of the masts and spars, &c. which were furnished at Boston to our vessels of war. Without the canal this part of the country could not have supplied these necessary articles.

In approaching the Concord river, the canal passes through half a mile of deep-cutting, 800 feet of which is excavated by blasting through a hard granite rock. In some places, this blasting was carried 7 feet into the rock, and from 14 to 20 feet wide. The deep-cutting for this half mile, is from 12 to 20 feet.

Across the Concord river, a few rods below the line of the canal, a dam 150 feet long and 8 feet high is made. This creates a pond, out of which, through the deep-cutting last mentioned, the water flows and supplies the canal 22 miles to Charlestown at the tide-water. From the other side of the pond the water flows through the canal 5 miles to the Merrimac river. The water which supplies the 22 miles of canal passes through a horizontal aperture of 6 feet by 1, with a head of 2 feet water above the upper side of the aperture. The towing-path is carried across the pond by means of a floating bridge, a part of which is occasionally drawn up to let the logs, timber, and drift wood, which collect above, pass through. There are two waste gates in the dam, by which the height of the water in the pond can, in some measure, be regulated.

In Chelmsford, within 60 rods of the Merrimac, is an aqueduct of which the abutments are 110 feet apart, and there are ten wooden piers to support it. The water in the aqueduct is 16 feet higher than the stream below. Between this aqueduct and the Merrimac is a fall of 32 feet, and 3 locks of durable stone masonry in tarras mortar. Where the canal joins the Merrimac, a basin is excavated, 10 or 12 feet below the natural surface of the earth, and 5 feet below the surface of the river at low water. The extent of the basin is about 200 feet on the shore of the river, and half that distance on a line at right angles with the shore, being nearly semi-circular. There are in all 7 aqueducts on the canal, but those not mentioned above are very inconsiderable: there are also several culverts. Grass grows in the bottom of the canal, and obstructs the passage of the water in autumn to such a degree, that at the lower end of the canal, 22 miles from its source, the water is sometimes 9 inches lower than it otherwise would be. To remedy this inconvenience, a man is employed, who wades along the canal, and mows off the grass under water with a scythe. During the winter season, while the canal was not used, the muskrats would sometimes burrow into and endanger the breaking of the banks; in consequence of which the company had offered a bounty of 50 cents for every one that should be destroyed within a certain distance of the canal. This bounty had caused their destruction to such an extent, that very little apprehension was entertained of their doing injury.

It was the original design of the company to employ three officers on the canal, viz. a superintendant, a treasurer, and clerk; but that project has been abandoned, and those three offices are now united in Mr. Sullivan. His compensation is a salary of $1500 a-year, besides 5 per cent. on all the tolls or receipts, which are warranted not to fall short of $20,000 per annum.

The receipts of the company from the canal are rapidly increasing. The income in 1808, was $7000, in 1809, $9000, in 1810, $14,000, in 1811, $17,000, last year $25,000, and this year (1816) it will, undoubtedly, exceed $30,000."

There are some other canals in Massachusetts, but of too little consequence to merit any particular notice.

Canals have been projected to unite Cape Cod bay with the Atlantic ocean and Buzzard's bay; the subjoined extract from Mr. Gallatin's Report on Roads and Canals, made April 4th, 1808, will amply explain the incipient advance of those plans at the period of that Report, and also at the present time, as no further measures have been adopted to carry such designs into effect.

"Sandwich Isthmus," says Mr. Gallatin, "between Barnstable bay, on the north, and Buzzard's bay, on the south, had first attracted the public attention. Surveys and levels were taken, for the purpose of ascertaining the practicability of opening a cross cut, to be supplied by the sea itself, from the mouth of Back river, in Buzzard's bay, to the mouth of Scusset river, in Barnstable bay.

The distance was found to exceed 7 miles; the elevation of the intermediate ground is 40 feet above low water mark, in Barnstable bay; the depth of water at the mouth of Back river does not, at low water, exceed 7½ feet; and the channel to that spot, through Buzzard's bay, is obstructed by shoals. The tide, which rises but 3½ feet in that bay, rises 3½ hours later, and more than 18 feet in that of Barnstable. The shore on which that formidable tide would operate is an open beach, without any harbour or shelter whatever. Independent of other obstacles, it was apprehended, that the same actual causes which had formed the isthmus might fill the canal, or make a bar at its entrance; and the project seems to have been abandoned.

2d. The ground was also examined between Barnstable harbour, on the north, and Hyannus harbour, on the south, at some distance east of Sandwich. The breadth of the peninsula does not here exceed 4½ miles, and there would be a harbour at each end of the canal. The same difference exists in the tides, which rise 4 feet in Hyannus, and 16 in Barnstable harbour. The entrance of this is obstructed by shoals; but the great obstacle to a cross cut is the elevation of the intermediate ground, estimated at 80 feet above tide water. Navigable ponds on that high ground might perhaps form part of a lock canal, and supply the remainder with water. But a canal frozen in winter would not have effected the great object in view, which was to enable vessels from sea to proceed, in winter, from Martha's Vineyard to Boston, without sailing around Cape Cod. Although the difficulty of the navigation from Boston to Barnstable diminishes the utility of this communication, as one of the great links of this line of inland navigation, it may be resorted to, should that which will be next mentioned prove impracticable for sea vessels.

3. The attention of the legislature of Massachusetts, under whose authority the grounds at Sandwich and at Barnstable had been examined, has lately turned to a direct communication, between Weymouth landing, within the harbour of Boston, and Taunton river, which empties into the bay of Rhode Island (Narragansett). A favourable report has been made during the last session, of which a copy has been obtained. The distance from tide water to tide water, is 26 miles by one route, and 23; by another. The highest intermediate ground is 133 feet above tide water, but may be reduced 10 feet by digging to that depth the length of a mile. Two ponds, known by the name of Weymouth and Cranberry, the largest and least elevated of which covers 500 acres, and is 14 feet higher than the summit of the proposed canal, will supply the upper locks with water by feeders 4 miles long. Whether the quantity of water contained in the ponds, and estimated equal to a daily supply of 450,000 cubic feet, will be sufficient for a sloop navigation, and whether any other ponds or streams may be brought in aid, does not seem to be fully ascertained. After descending 20 feet towards Weymouth, and 70 towards Taunton, an ample supply for the lower locks will be derived from other large ponds, the principal of which are known by the names of Braintree, and Nippinitic.

The expense may, on a supposition that the route is partly through a rocky soil, be estimated as follows:

Digging 26 miles, at 30,000 dollars a mile - -	$780,000 00
Lockage 260 feet, at $1250 a foot - -	325,000 00
Feeders, purchase of land, &c. - - -	145,000 00
	$1,250,000 00

There have been no canals executed or designed, hitherto, in Rhode Island or Connecticut, worthy notice in a general view. We pass on to the greatest works of that nature ever planned in America, the grand Canals of New York.

We cannot preface what we intend to give to the public on the important topic of the New-York canals, better than with the two following letters.

Albany, February 22d, 1822.

Dear Sir—Shortly after the receipt of your last letter, I was by the canal commissioners ordered on to the northern canal, to examine a new plan for a feeder, which has made it impossible for me to give the attention to your queries concerning our canals, which I intended. From what I shall send you may perhaps pick out something that you will use.

"At what period, and by whom, was either of the New-York canals designed?" Canals between the Hudson and northern Wood creek, and between the Mohawk and western Wood creek, must have been contemplated by the first navigators of those waters; things so obvious must have early struck every one, but the idea of the Erie canal is of very modern origin. In the winter of 1804, I learnt for the *first time*, from the surveyor-general, that Mr. Governeur Morris, in a conversation between them in the preceding autumn, mentioned the scheme of a canal from lake Erie across the country to the Hudson river. The idea of saving so much lockage by not descending to lake Ontario, made a lively impression on my mind, by which I was prompted on every occasion to inquire into the practicability of the project, and entered with enthusiasm on the task assigned me by the surveyor-general in 1808, of expending the small sum of six hundred dollars, then granted by our legislature, "for making levels," &c. After spending the money and summer of that year in examinations between lake Erie and Ontario, Mud creek and Sodus bay, Oneida lake and Ontario, &c. the spot of great difficulty and uncertainty respecting our *inland route*, remained unexamined, to wit, the tract between Genesee river and Palmyra, or head waters of Mud creek, and the hopes from a view of maps discouraging indeed. Where was the water to be got for locking over the high land that was supposed to rise between Genesee river and Mud creek. All knowledge of an interior route was incomplete, while this piece of country remained unknown. In December of that year, I again left home for the above object, and after discovering at the west end of Palmyra that singular brook which divides, running part to Oswego and part to the Irondequot bay, I levelled from this spot to the Genesee river, and to my great joy and surprise found the level of the river far elevated above the spot where the brooks parted, and no high land between. But to make the Genesee river run down Mud creek, it must be got over the Irondequot valley. After levelling from my first line 1½ mile up the valley, I found the place where the canal is now making across that stream at Mann's mills. This formidable obstruction I examined, levelling over where the canal is now making, and over the mill-pond, from which surveys I made the map of which I send you a copy.

The passage of the Irondequot valley is on a surface not surpassed, perhaps in the world, for singularity. No adequate idea can be conveyed without a map. Those ridges along the top of which the canal is carried, are in many places of just sufficient height and width for its support, and for 75 chains the canal is held up, in part by them, and in part by artificial ridges, between 40 and 50 feet above the general surface of the earth; the sides of them are in most places remarkably steep, so that when the work is finished, the appearance to a stranger will be, that nearly all those natural embankments were artificial works. At A, the base of the ridge is so narrow, that for some chains stone walls are built on each side, to keep the earth from filling the roads at its base. The arch through which the stream passes under this stupendous embankment is 26 feet span, 17 feet high, and 245 feet long, resting upon nearly 1000 piles, some of them driven 20 feet. The surface of this wooden foundation is just 70 feet below the top-water line of the canal. At B the ridge is higher and wider than is needed for the support of the canal, and the view to the south obstructed for a short distance. The red figures on the map show, in feet, the elevation of the place where they are, above the surface of the mill-pond; the whole country thinly timbered with oak. While traversing these snowy hills in December 1808, I little thought of ever *seeing* the Genesee waters crossing this valley on the embankment now constructing over it. I had, to be sure, lively presentiments, that *time* would bring about all I was planning, that boats would one day pass along on the tops of these fantastic ridges, that posterity would see and enjoy the sublime spectacle, but that for myself, I had been born many, very many years too soon. There are those, sir, who can realize my feelings on such an occasion, and can forgive, if I felt disposed to exclaim *Eureka*, on making this discovery. How would the great Brindley, with all his characteristic anxiety to avoid lockage, have felt in such a case: all his cares at an end about water to lock up from the Genesee river, finding no locking up required. Boats to pass over these arid plains, and along the very tops of these high ridges, seemed then like idle tales to every one around me. Seventy-three dollars was afterwards allowed by the legislature in addition to the six-hundred.

The east end of lake Erie, where the canal boats and lake vessels shall come together, will one day become a very important spot. To understand its particular localities a map is indispensable. Great difficulties attend getting a spacious harbour at this place, and a very spacious one will be required. From examinations made last fall, I have made myself so well acquainted with every thing relating to this place, as to abandon my former plan of making an harbour by uniting island to island, by mounds, as published by Mr. E. Watson. At present, I propose to have the canal terminate opposite the lower end of Squaw island, at which place, let the island be connected with the main shore, by a dam raised to the level of the lake, which is from 3 to 4 feet higher than the river's surface at this place. After raising such parts of the island as are too low, to the lake level, run a mole from the upper end thereof, in length about 1¾ mile to the surface of the lake, a little above Bird island, the height of which mole shall correspond with the level of the lake. About 4 chains from the shore, on an average, is as far out as this mole ought to be built, that sufficient water way may be still left in the Niagara river. The surface between Squaw island and the shore is almost 80 acres, with 56 between the mole and the shore, is 136 acres. But in all probability, this harbour will in a short time be insufficient for the boats and sail vessels that will crowd into it in the spring season. A lock will then be wanted to lock out into the river where it is still and deep, below Black-rock rapid, and such a lock is now much wanted for the use of all such vessels as are by stress of weather, driven through the British channel down the rapids, for the purpose of locking them up to the lake level again.* At present, these vessels are drawn up by 15 or 20 yoke of oxen. Out of this harbour a branch canal can be made to Buffaloe village. The creek here is, for 1¼ mile in length, on an average 3 chains wide, deep enough for lake vessels. This makes but 30 acres, not quite equal to one of the East India docks, artificial works in London. In Mr. Hayne's "Introduction, &c." lately published, he says, "when the destinies of the western country are "duly considered, and the riches of our own state are "duly appreciated, it is no visionary calculation to say, "that a million of tons (annually) will pass through the

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* For no vessel, in a storm, can enter either the harbour here described, or the one constructing at Buffaloe.

"western canal in the course of a few years." And, if a few years will do all this, what shall *time*, bringing on these destinies with an accelerated velocity, accomplish, before all the eyes of the present planners shall be for ever closed.

The annual report of our canal commissioners will in a few days be published, from which the present state of the canals will be seen; I will, sir, send you a copy as quick as it is in my power, and shall regret much if your printer shall not allow time for you to see said report in season to avail yourself of it.

Some things that I have dwelt upon may not interest you, as I may have expected. The Irondequot embankment will I think receive the admiration of all visitors. I have seen, sir, the famous Harper's ferry on the Potomac, and with the philosopher of Montocello, could see, when finished, said embankment, trusting he would pronounce it a sight still more worth a voyage across the Atlantic. On the highest part of the peninsula, what a site for a Belvidere.

If I print any more of my maps of the Champlain canal, there shall be laid down on it the new proposed feeder, between 6 and 7 miles long, intended as a canal past Glen's-falls and Baker's-falls.

Respectfully, I am, Sir, your most obt. servant.
J. GEDDES.

Albany, Feb. 25, 1822.

DEAR SIR—Mr. Geddes has presented your compliments to me, from a letter to him requesting materials relating to our canals, to be introduced into the Encyclopædia. I will give a brief sketch of what was done in relation to them, anterior to the period which has furnished the documents published by Mr. Haines.

A considerable discussion, as you know, has appeared in print, about the origin of the Erie canal, with the view of ascertaining who is most entitled to the honour of it. The following statement of facts will, I believe, enable the public to form a correct opinion on that point.

Soon after the revolutionary war, the attention of our legislature was drawn to the improvement of the internal navigation of the state, and two companies were incorporated for the purpose, to wit, the "Northern," and "Western Inland Lock Navigation Companies." With respect to the latter, the views of its patrons evidently did not extend farther than to the improvement of natural streams, and the making of short canals and locks to pass difficult or unnavigable places, such as the Little Falls on the Mohawk river, the communication between that river and the Wood creek at Rome, and some extraordinary rifts or rapids, in order to facilitate the passage of boats from Albany, or Schenectady, to Oswego, and the Cayuga lake. Beyond these nothing was then contemplated. To lock round the Niagara falls was a subsequent project, which was never attempted to be put into execution. The merit of first starting the idea of a direct communication by water, between lake Erie and Hudson's river, is unquestionably due to Mr. Gouverneur Morris. The first suggestion I had of it was from him. In 1803, I accidentally met with him at Schenectady. We put up for the night at the same inn, and passed the evening together. Among the numerous topics of conversation, to which his prolific mind, and excursive imagination, gave birth, was that of improving the means of intercourse with the interior of our state. He then mentioned the project of *tapping lake Erie*, as he expressed himself, and leading its waters, in an artificial river, directly across the the country to Hudson's river. To this I very naturally opposed the intermediate hills and valleys, as insuperable obstacles. His answer was, in substance, that *labor improbus omnia vincit*, and that the object would justify the labour and expense, whatever that might be. Considering this as a romantic thing, and characteristic of the man, I related it on several occasions. Mr. Geddes now reminds me that I mentioned it to him in 1804, when he was here as a member of the legislature, and adds that, afterwards, when in company with Mr. Jesse Hawley, it became a subject of conversation, which probably led to inquiries, that induced Mr. Hawley to write the essays which afterwards appeared in newspapers, on the subject of carrying a canal from lake Erie to Albany, through the interior of the country, without going by the way of lake Ontario. In 1808, our legislature adopted a resolution, proposed by Mr. Joshua Foreman, a member from Onondaga, "directing the surveyor-general to cause an accurate survey to be made of the rivers, streams, and waters (not already accurately surveyed) in the usual route of communication between the Hudson river and lake Erie; and such other contemplated route as he may deem proper," &c. In pursuance of this resolution, after I had got all the information I could obtain by epistolary correspondence, I commissioned Mr. James Geddes, who has since been continued as an engineer on the canal, to make surveys, and take the levels which the nature of the business required. My instructions were, that he should examine whether a canal could be made from the Oneida lake to lake Ontario, where Salmon creek enters it. This route had been represented as probably practicable, but was soon found impossible. Mr. Weston, the British engineer who had some years before been employed by the Inland Lock Navigation company, had reported the navigation from the Oswego falls to lake Ontario, along the Oswego river, as hardly susceptible of improvement by means of canalling. I therefore directed a route to be explored on the west side of the river, which had been favorably represented. This was done by Mr. Geddes, and a practicable route reported. He was next to level round the Niagara falls, and ascertain the best line of a canal from above the falls to Lewistown. This was also done; besides which observations were made on the descent of the Niagara river from lake Erie to the falls.

But the most important business remained yet to be done, and for doing which, in a manner much to be desired, we had not adequate means, the money appropriated for all that was directed by the resolution being only six hundred dollars. What remained to be done was to ascertain the practicability, and most direct route of a canal from lake Erie to the Genesee river, and thence to the waters running east to the Seneca river. As our scanty allowance, when we had got thus far, would probably be nearly exhausted, Mr. Geddes was instructed to do this as well as it could be done, by mere inspection, without the use of instruments; and to collect such information as might be useful in a further prosecution of the business, should the legislature think proper to provide for it. I had received such information from Mr. Joseph Ellicott, the Holland Land company's agent, as satisfied me that a canal was practicable from the Niagara to the Genesee river, by following the valley of the Tannewanta to the summit, from which a descent might be made to the east; but other parts of the country were also to be explored, in order to ascertain which, of all practicable routes, would be most eligible, and this resulted in a report of one almost precisely in the line, which, after repeated elaborate and expensive examinations, has been finally adopted. Mr. Geddes was directed more particularly to pay attention to that part of the route which laid between the Genesee and the waters running east into the Seneca river. Here some of the most difficult passes occurred, and levels were taken to ascertain the best manner of getting over them, which was specially noticed in the report, and followed, with but little deviation in the final location of the canal. From the Seneca river, in the Cayuga valley, to the Mohawk river at Rome, and thence to Hudson's river, the make of the country is so well known, as to leave no apprehensions of insuperable difficulties. Thus then was, by the operations of 1808, the fact satisfactorily established, that a canal from lake Erie to Hudson's river was not only practicable, but practicable with uncommon facility.

The favourable light in which the report of this year's work presented the projected enterprise, after encountering prejudices from various sources, and oppositions made for various reasons, induced the legislature, in 1810, to organize a board of commissioners, with powers and means to prosecute the business. The commissioners were, *Gouverneur Morris*, *Stephen Van Rensselaer*, *De Witt Clinton*, *Simeon De Witt*, *William North*, *Thomas Eddy*, and *Peter B. Porter;* to which were afterwards added, *Robert R. Livingston*, and *Robert Fulton*. Under this commission, the exploring surveys commenced in 1808, were continued under the direction of the surveyor general, and preparatory measures concerted for ulterior effective operations. Mr. Geddes was continued as the engineer, to prosecute the examination of the country, with the view of permanently locating the canal. In this year he ascertained the place where the important passage might be made from the Tannewanta creek through the ridge which bounds it on the north, whence the country is on a continued descent to the Genesee river. By this means was avoided the very considerable additional length of canal, which would otherwise have been necessarily caused by a circuitous route along the Niagara valley to the neighbourhood of Lewiston, before it could take its eastern direction along the northern declivity of the ridge. The commissioners were prevented from the effectual execution of their plans by the occurrence of the late war. Since which the history of proceedings relating to the canal may be collected from the documents which have already been published.

I have thus given you a very condensed representation, or rather a loose *outline* sketch, of the inceptive operations which led to the serious undertaking of what we now call, with a justifiable pride, our GRAND CANAL. The official report of the transactions of 1808 is composed in about sixty close written large quarto pages, with the necessary explanatory maps; and remains deposited in the secretary of state's office.

I am, very respectfully, your obed't h. serv't,

S. DE WITT.

Mr. William Darby.

The following report was made by the Board of Commissioners, named in the foregoing letter, in the month of February, 1811, and we insert it entire, as the first great act towards the actual canal operations, and a very important link in the chain of canal history in the state of New York. The commissioners observe:

That they have examined the country as critically as time and circumstances would permit, and caused surveys to be made for their better information.

They beg leave to observe, on the present navigation of the Mohawk river, Wood creek, Oneida lake, and the Oswego river, which extend from Schenectady to lake Ontario, (saving only a portage at the Falls, within twelve miles of Oswego,) that experience has long since exploded in Europe the idea of using the beds of rivers for internal navigation, where canals are practicable. The reasoning on that subject applies with greater force in America. For, in the navigation of rivers, reliance must be had principally on the labour of men; whereas, along canals, the force employed is generally that of horses. But the labour of men is dearer, and the subsistence of horses cheaper in America than in Europe. Experience, moreover, has, in this country, declared against following the course of rivers, more decidedly than in the old world; for there, notwithstanding the excellence of the highways, transportation is performed (between Rouen and Paris, for instance) in boats drawn up the river: but along the Mohawk, though the road from Schenectady to Utica is far from being good, it is frequently preferred to the river.

By the aid of canals, a good navigation (for boats) can unquestionably be made from Schenectady to the Falls, in Oswego river, twelve miles south of lake Ontario. From Schenectady to the Hudson, and from the Falls just mentioned to the lake Ontario, a boat navigation is also practicable; but whether it be advisable, may deserve consideration.

A preliminary point to decide is, whether, by this route, vessels can be taken across, of size and form to navigate, with advantage, lake Ontario and Hudson's river; such, for instance, as sloops and schooners of fifty or sixty tons.

The commissioners believe this to be impracticable, from the want of water at the summit level. Whether a sufficient supply even for boats can be obtained in a dry season, should the whole trade of the great lakes be turned that way, is a matter worthy of consideration.

Admitting, however, that the boat navigation were completed to the Falls, in Oswego river, and a sufficient supply of water secured, it remains to inquire whether it would be prudent to expend what may be needful on the navigation between those Falls and the lake.

It will be seen by the report of the surveyor hereunto annexed, that in this distance there is a descent of little less than one hundred feet, and that the circumstances are peculiarly unfavourable; so much so, that an intelligent practical man (Mr. Weston) formerly pronounced it impossible. That word, however, when used on occasions of this sort, must be understood as standing in relation to the means which can prudently be applied to the end.

In examining the amount of expenditure which prudence may justify, it is to be noted, that if the same boat which arrives at the upper end of the Falls, could, after reaching Oswego, proceed on her voyage, it might be worth while to calculate whether the saving of time and expense in lading and unlading, would bear any rational proportion to the cost of completing that navigation; but that is not the case, and therefore it would be more advisable, if the communication be deemed of sufficient importance, to construct a rail-way.

This, according to the estimate of an intelligent and experienced man, (Mr. Latrobe,) annexed to Mr. Secretary Gallatin's report on canals and roads, would cost about 10,000 dollars per mile; and by the aid of it one horse could transport eight tons, supposing the angle of ascent not to exceed one degree.

But an angle of one degree will ascend in a mile upwards of ninety-two feet, or nearly as much as the difference of level in the whole twelve miles. If, then, two dollars be allowed for a horse, waggon, and driver's wages, (with such return load as he can procure for his profit,) and ten cents be allowed for the use of the railway, and if it be supposed that only five tons be taken, instead of eight, the cost will be for each ton, the twelve miles, forty-two cents, or three and a half cents per mile; at which rate, one hundred and forty miles (a greater distance than between Oswego and Lewiston, along lake Ontario) would come to four dollars, ninety cents, being thirty-five cents less than the freight now paid.

A question, however, of more importance presents itself. Admitting that it were easy to complete a boat navigation from Rome to lake Ontario, and more difficult and expensive (in comparison) to effect a canal navigation to lake Erie, would it not be advisable to descend into lake Ontario, rather than encounter the difficulty and expense of the other course?

The commissioners believe it would not; and without relying, as they might, for support of their opinion, on the comparative expense of transportation, (a topic which will find a better place elsewhere,) it is sufficient to say, here, that articles for exportation, when once afloat on lake Ontario, will, generally speaking, go to Montreal, unless our British neighbours are blind to their own interest; a charge which ought not lightly to be made against a commercial nation.

Freight from Niagara to Oswego will, from the difficult and dangerous access to that harbour, be as high as to the head of the rapids in the river St. Lawrence. The descent from thence to Montreal is less than the ascent from Oswego to Rome. It is true, that the lake Ontario is estimated at one hundred and ninety-six feet above tide water, and the Rome level only one hundred and eighty-four feet above the lake: but there is a considerable descent in the river St. Lawrence, in a distance of about seventy miles, to the lower end of the present sloop navigation, through which the current is sometimes strong. There is also a considerable descent from Montreal, in a distance of about thirty miles to tide water in the lake St. Peter's. Perhaps it will be found that an average allowance of three inches per mile, (in the whole upwards of twenty feet) is not too much, and that the river at Montreal is not one hundred and seventy feet below the upper surface of the Gallot's rapids. In the distance of one hundred miles between these places, there are forty of still water, viz. about thirty in lake St. Francis, between the foot of Long Saut and the head of the Coteau du Lac rapid, and upwards of ten in the lake of the Two Mountains, between the foot of the cascade at the cedars and the La Chine rapid.

Thus there will remain but sixty miles of canal, with an average fall of thirty-four inches per mile. The land descends proportionately to the water, so that there can be but little deep cutting; the soil is easy to dig; there are no streams or ravines of any consequence to cross; and there is an inexhaustible supply of pure water, which never varies much in its height, for any canal whatever.

Under circumstances so propitious, it is probable that a good sloop navigation, from above the gallots to Montreal, would cost less than a good boat navigation from Oswego to Rome. The extent of this last, deducting the Oneida lake, is fifty-six miles; the fall is on an average near forty inches per mile; the supply of water is doubtful, and in twelve miles of the distance, obstacles almost insurmountable present themselves.

These are facts to which it would be in vain for the citizens of the United States to shut their eyes. The eyes of a rich enterprising commercial rival are open; and when it is considered that (if the means of easy export be supplied to the inhabitants who may settle near the great lakes) that country will, in no distant period, furnish a more abundant stock of commodities for foreign trade, than is now sent from all the Atlantic ports of the union—it would be absurd to doubt, whether, in the competition for that commerce, our neighbours will employ the means in their power. Nor must it be forgotten, that the revenue which, under present circumstances, is raised from commerce, and which no probable change will reduce below an ad valorem duty of ten per cent. cannot but operate in favour of our rivals. True it is, that as far as regards the pecuniary benefit of those who may settle along the lakes, the route by which their products are sent abroad, and their supplies of foreign articles introduced, must be to them a matter of little consequence. But the political connexion which would probably result from a commercial connexion, certainly deserves the consideration of intelligent men.

The commissioners have no doubt, that obstructions at the mouth of Oneida lake may be removed, so as to lower the surface of that lake from eighteen inches to two feet, at no great expense, and with little, if any injury to the navigation. But they have not been able to satisfy themselves that the lands contemplated in the petitions which the joint resolutions refer to, would be in any wise affected by operations at the mouth of Oneida lake. According to the information they have obtained, these lands are inundated by the waters of Butternut, Limestone, Chitenengo, and Canaserago Creeks, obstructed before their entrance into the lake.

In respect to an inland navigation direct from lake Erie to Hudson's river, the commissioners beg leave to refer for information to the annexed reports and maps of Mr. James Geddes, employed at their request by the surveyor-general. From these it is evident that such navigation is practicable. Whether the route he sketched out will hereafter be pursued; whether a better may not be found—and other questions subordinate to these, can only be resolved at a future time, when an intelligent man, regularly bred to this business, shall, under the direction of those on whom the public may think proper to devolve the superintendance, have made a more extensive and careful scrutiny than the time and means of the commissioners would permit. They conceive, however, that it may not be improper to say a few words on the topography of the country, which may be divided into three parts, nearly equal.

The Mohawk river, as is well known, runs in a deep ravine, and there is, generally speaking, along its banks, a vale of rich soil. In different places, however, spurs from the neighbouring hills project themselves to the edge of the river. On the north side fall in sundry small streams, and two, (the east and west Canada creeks,) which are large and copious, especially the latter. They are both rapid, and run in deep ravines. On the right side, also, there are several tributary streams. The most considerable of these is the Schoharie, which, rising among the Catskill mountains, has scooped out, with its impetuous waters, a wide and deep ravine.

The stream next in importance, coming in from the south, is the Oriskany, which is especially valuable, because it enters the river not far from the summit level at Rome, and may, perhaps, become useful as a feeder. This forms the first eastern, or river division, in which navigation, though defective, already exists. In this division, with proper management, there will be no defect of water for a boat canal, unless, perhaps, in very dry seasons, at the summit level.

The second, middle, or lake division, extends from the summit level westward to the outlet of the Canandarque lake. In it lie four lakes, the Otisko, Skeneateles, Owasco, and Canandarque, higher than any canal which may be extended from lake Erie to the Hudson, and furnishing a copious supply of water. Of the two largest lakes, the Seneca, increased by a stream from Crooked lake, lies nearly on the same level with Rome, but the Cayuga much lower.

In this division the turnpike road crosses high hills, but they all terminate not far north of it, leaving a large deep valley, upwards of eighty miles long, from east to west, and about twenty wide, from north-west to south-east. If, indeed, the Cayuga lake, embosomed in a ravine which opens to the north on the valley, be considered as part of it, the breadth will be fifty miles. In this valley lie the Onondaga, Cross, and Oneida lakes. It is bounded on the north by a dividing ridge of land, which stretches from near the Gerundegat bay, eastwardly, to the neighbourhood of Rome, where it joins the dividing ridge north of the Mohawk, between the waters of the St. Lawrence and those of the Hudson.

The third, western, or dry division, extends from the western boundary of the lake Division to lake Erie. In this, although the Genesee river runs through it, a want of water is already felt, and will daily become more sensible, as the country is cleared. The Genesee river, itself, is a torrent, which, however copious, or even superabundant, it may be in the spring, is in the autumn almost dry. This tract of country, especially after passing the flats of the Genesee, may, with little violence to the propriety of language, be called a plain: and here it may be proper to notice a peculiarity in the shape of the northern, and much of the western, part of the state, which distinguishes it widely from the country lying south-east of the mountains.

The descent from the dividing ridge, northward, is generally by a gradation of plains,* nearly horizontal. These, and the streams by which they are watered, have a similar, and, as it were, a simultaneous descent. Thus the rivers are but a kind of lakes, lying in plains, and communicating by falls and rapids with each other. These gradations have sometimes a small rise, immediately before descent; at other times, in ascending from one, we come immediately to the other. In no case is the peculiarity of shape more worthy of remark, than at the cataract of Niagara. In coming from lake Erie, where the sight cannot reach over the expanded surface, proceeding along the level bank of the Niagara river, to the head of the rapids immediately above the falls, and thence pursuing a northern course, the traveller ascends but thirty-eight feet, before he descends three hundred and forty-five, to the plain in which lake Ontario is stretched out, from east to west, upwards of one hundred and sixty miles. The surface of lake Erie is three hundred and twenty-nine feet above that of lake Ontario, which, being taken from the whole descent just mentioned, leaves for the rise of land between those two great reservoirs, but sixteen feet.

This rise, and others similar to it, are called by the inhabitants, the ridge, the ledge, the slope, and the hill. A more proper general appellation, perhaps, is, the steep, though occasionally, by the elevation each way, it becomes truly a ridge, or, from the horizontal strata of stone, as truly a ledge. In some places the descent is by a gentle slope; in others, more precipitous; and in some, almost perpendicular. Two of these extend eastward from the shore of Niagara river, nearly parallel to, and distant from each other about fourteen miles. The higher, or southern steep commences at Black Rock, where the river issues from lake Erie. The northern commences at the falls, and, after an eastern course of fifty or sixty miles, bends towards, and approaches the southern, after which they both take a southern direction for thirty miles, but return again on the east side of the Genesee: or, to speak more correctly, that river, after breaking through them by successive falls of sixty and ninety feet, thirty miles south of the high road, in the township of Leicester, runs in a ravine to the northern part of that township; when the steeps again diverge, the southern stretching eastwardly to the west side of Seneca lake, and then southerly, to the high grounds from whence flow the waters of the Tioga; while the other keeps an eastern direction, to the hills from whose southern declivities flow the Chenango and Unadilla. There is another steep still more north, which branches out from that last mentioned, near the Eighteen Mile run, (a stream whose mouth is at that distance from that of the Niagara river,) and diverging northward, is, for some distance in its eastern progress, indistinct. It extends, however, to the lower falls of the Genesee, and is there crossed by that river, as also, beyond it, by streams, which fall into the Gerundegut bay; after which it becomes properly a ridge, and extends beyond the falls of Oswego river, as has been already mentioned. Of these three steeps, ledges, or ridges, the most southern is distinguished by limestone mixed with flint. The middle, by the same stone mixed with shells, and the most northern, by freestone and slate. Over the southern steep, west of the Genesee, fall Ellicot's brook, and the Tanewanta, (which enter Niagara river by the same mouth, opposite to Grand Island,) also, Allen's brook, which makes, at its passage, the Buttermilk Falls, and runs to the Genesee. Over the middle steep, in the same division, falls the Oak-orchard brook, which enters lake Ontario about thirty miles east of Niagara river. The lower falls of this brook, as well as those of the Genesee, are over the northern steep.

The Canesus, the Hemlock, the Honeyoyo, the Canandarque, and the Crooked lakes, lie south of the southern steep. The Seneca, the Owasco, the Skeneateles, and Otisco lakes, lie south of the middle steep. North of which lie the Cayuga, Onondaga, Oneida, and Cross lakes.

The Tonawanta falls over the southern steep twenty-five feet, and, passing the village of the same name, runs in a level valley of brown clay upwards of twenty miles to its mouth in Niagara river.

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* The word *plains* might lead into error. It is therefore proper to state, that hills are scattered about, which vary the surface to the eye. But, on examination, it will be found that, generally speaking, their bases are all on the same extended plain.

From the Tonawanta village, north-eastward, in less than five miles, (chiefly through a swamp) the Oak-orchard brook receives the waters of the swamp, and falls, as has been already mentioned, into lake Ontario. The Tonawanta brook, three feet higher than the swamp, is separated from it by ground, whose elevation is not more than five feet; the distance is short of a mile, and the soil being clay, it will be easy (by turning its waters into Oak-orchard brook) to convert the Tonawanta from its mouth, upwards, into a canal. It has, above eleven miles from its mouth, a depth of twelve feet, interrupted, nevertheless, by five bars, or shallows, composed of round stones, buried in clay. During this space, the breadth is in general forty yards, though in the narrowest part not more than thirty. The first shallow, about three miles from the mouth, is called Miller's Ford, and is not above 12 yards wide; the next, about a mile beyond it, called House's Shallow, extends east and west nearly one hundred and twenty yards; the depth of water from two and a half to three feet. Two miles farther up is Christman's Rapid. This extends east and west near two hundred and fifty yards, with a depth of from fifteen to eighteen inches: at this rapid, the fall is three inches, except when a westerly wind brings up the water of lake Erie. The breadth of the Tonawanta is here forty-eight yards, and no where below it less than forty.

The next bar, about a mile from the last, is called Van Slyke's Shallow; it extends forty-two yards; the depth in the shortest place twenty inches, but in general from two to three feet. The fifth and last bar, at eleven miles from the mouth of the creek, extends near one hundred and eighty yards, and has from one to two and a half feet of water.

To convert this water-course into a canal twelve feet deep, during the whole distance of eleven miles, will require, at most, an excavation of eighty thousand cubic yards. The surface here is four inches higher than at the mouth, which is five feet lower than the surface of lake Erie. At about five miles and a quarter north from this place, in the middle steep, is the source of one branch of the Eighteen Mile brook, at a distance of about ten miles from lake Ontario, and about three hundred feet above its surface; consequently, near thirty feet below the surface of lake Erie. The greatest elevation of ground between them is twenty-one feet above that surface; it is, however, on an average, for the space of three miles, twenty feet, and the remaining two miles and a quarter, about seven feet.

For a more particular knowledge of the ground, reference must be had to the profile made by Mr. Geddes, and which is hereunto annexed. It is self-evident, that the cost of excavation, per cubic yard, must depend on the substance in which the excavation is made; it must depend, also, on some other circumstances. In deep cutting, for instance, not only must there be wide cutting, to prevent the earth from falling in, but there will be, generally speaking, more labour, and consequently more expense, in moving the earth after it is dug. It may become, therefore, in many cases, more advisable to pierce the earth by a tunnel, than to take down the top of a hill.

In the present instance, by means of wooden railways, which may be constructed from the surrounding forests, for temporary purposes, at a trifling expense, the materials may, when dug, be made, as it were, to transport themselves along, by gentle declivities, to fill that part of the ravine through which the canal is to pass.

In the construction of canals, when recourse is had (as must generally be the case) to rivers, for a supply of water, it is found necessary to guard with scrupulous care, and, not unfrequently, at enormous expense, against those floods, which, pouring a torrent into a canal, and tearing down its banks, might at once destroy the navigation, and inundate the country.

Moreover, it is found that canals depending on rivers, frequently, like the rivers themselves, want water in the season when it is most necessary. Indeed, to suppose the quantity of water in a river, when turned into a canal, will remain the same, would lead to serious disappointment. Much must be allowed for evaporation, and, notwithstanding the utmost care, more will filter through the sides and bottom of a canal than those of a river, which are generally saturated.

Thus, then, two prominent evils present themselves in feeding from rivers, viz. In spring, they pour in too much water, and can afford none in autumn, when it is most wanted. There is still another evil, which, though not so imminent, becomes eventually of serious moment. When the country shall be cultivated, streams, swoln by showers, will bring down, mixed with their waters, a proportion of mud, and that, in the stillness of a level canal, will subside, and choke it up. It is also to be noted, by those who shall construct canals in this country, that the true character of a river cannot now be known. Large tracts, (for instance, west of the Genesee) which appear as swamps, and through which causeways of logs are laid for roads, will become dry fields, when no longer shaded (as at present) by forests impervious to the sun.

In the progress of industry, swamps (the present reservoirs of permanent springs that burst out on a lower surface) will be drained, whereby many of those springs will be dried. Of such as remain, a part will be used to irrigate inclined plains.

Moreover, in every place, tolerably convenient, ponds will be collected for mills and other machinery, from whose surface, as well as from that of the soil, the sun will exhale an ample tribute of vapour.

Thus the summer supply of rivers will be in part destroyed, and in part consumed, whereby their present autumnal penury must be still farther enhanced. But in the spring, the careful husbandman and miller will open every ditch and sluice to get rid of that water, which, though at other times a kind friend and faithful servant, is then a dangerous enemy and imperious master. Of course, much of what is now withheld for many days will then be suddenly poured out. The torrents must therefore rage with greater fury hereafter than they do in the present day.

Considerations like these, while they cast a shade over many contemplated enterprises, give by contrast a glowing hue to that which we have now to consider. The canal from Lake Erie to the Hudson, may be fed by pure water from lakes, provided mounds and aqueducts be made over intervening valleys, or the canal be carried round them. In every case the attending circumstances must decide.

In general, also, it is only after a more acute examination of the ground by a skilful engineer, well practised in such business, that the best mode can be adopted for the species of navigation which may be ultimately determined on, viz. Whether for vessels which navigate Hudson's river and Lake Erie, or for barges of from twenty to sixty tons.

If the passage were only of a few miles, the propriety of bringing vessels of eight feet draught of water across (if practicable) would be readily admitted. But it may well be questioned, whether, to save the expense of lading and unlading at each end of a canal three hundred miles long, the expense of cutting two yards deeper than would otherwise be necessary ought to be encountered.

It has generally been assumed, and perhaps too lightly admitted, that canals should be made on a perfect level. This axiom would not be questioned, if the transportation, each way, were of equal burden; if the distance or the frequency of good feeding streams were such as easily and constantly to supply, without danger of excess, the incessant waste of water by absorption, leakage, and evaporation; and if the waters to be connected were on the same level. But in a case like the present, rational doubts may be entertained. The difference of level being upwards of five hundred feet, all the descent which can prudently be obtained by an inclined plane is so much saved in the expense of lockage; and, in all human probability, the transportation, for centuries to come, will be of so much greater burden from the interior country, than back from the sea, that a current from the lake is more to be desired than avoided, more especially as it will in some degree counteract the effect of frost. That inexhaustible stream of limpid water which flows out of lake Erie, with little variation of height to endanger the canal, is a strong temptation to use it exclusively, until auxiliary supplies can be drawn from other reservoirs equally pure. Nor is it improper in this case to remark, that it is impossible there should ever be a considerable variation in the surface of Niagara river, at the mouth of the Tanawanta. No supposable fall of rain, or melting of snow, even if both were to take place at the same time, in the country which surrounds the great lakes, could raise, in any considerable degree, their extended surface. Indeed, we know, from experience, that a greater difference of elevation at the mouth of lake Erie is occasioned by a change of wind, than by any variation of the seasons. Admitting, however, a considerable rise of water, no matter from what cause, at the source of Niagara river, it cannot suddenly, from the narrowness and shoalness of the channel, produce a correspondent rise at the foot of the Black Rock rapid; and the elevation there must, in the nature of things, exceed that which is occasioned by it fifteen miles lower down; more especially as the river, including the two channels round Grand Island, has, for the greater part of the way, nearly three times the breadth which it has above. If, however, it were only a deep bay, the water, pressed forward by the wind, would be piled to a considerable height; but instead of that, the river here, with a breadth fully double to what it has at Black-Rock, precipitates itself over the first ledge in its headlong course to the cataract: so that an increase of height is instantly counteracted by the increased rapidity with which it rolls over the rock.

In all events, it would be advisable to use this water exclusively for a great part of the way, even if the country afforded other resources; and to this effect, there must be some descent in the canal. What the precise amount of that should be, in every mile, the commissioners presume not to say. They do not pretend to sufficient knowledge on the subject, and with all proper deference refer it to a practical engineer.

Nevertheless, like other men possessed of common discernment, they perceive not only that the quantity of water which runs in a given time must be proportionate to the rapidity with which, and the aperture through which it passes; but also that the rapidity itself will depend not merely on the declivity, but also on the mass; because, in a deep and wide channel, the friction must be less than in one that is narrow and shoal. It will depend also on another circumstance, whose effect (that single cause remaining the same) will vary, according to such of the preceding circumstances as may be connected with it. Admitting, for instance, a stream to be deep and wide in descending an inclined plane, its velocity will be accelerated. But if the inclination be not great, and the channel shoal and narrow, the friction may so counteract the descent as to retard the velocity.

From these considerations it is evident, that the sum of descent must depend primarily on the quantity of water required. This, in navigation ascending and descending by locks, must be greater than when carried along the plain. It must also be greater in a loose than in a stiff soil. Moreover, the quantum of descent required, must, after the needful supply of water is ascertained, depend on the length, the width, the depth, and finally on the course of the canal, whether direct or serpentine. And here the same common sense presents another important consideration. The amount of rapidity which may with safety be hazarded will depend on the texture of the substance through which the current passes. No navigable velocity can injure a rock of granite; but a gentle current will sweep off the substance of bog meadow. In like manner, banks which resist when the course is direct, may be eaten away, and the current itself be retarded, if propelled along a tortuous course.

The commissioners cannot, therefore, too often repeat, that their report must be accepted as suggestions proceeding from a superficial view, and not as conclusions founded on sufficient and scientific investigation. After this preliminary caution, they assume hypothetically that a canal were run in such manner, as that the average descent were six inches in every mile. Whence, taking the surface of lake Erie as the standard level, they have in gross the following results:

From lake Erie to

	Miles.	Descent.	Total descent.	Actual descent.
The mouth of Tanawanta,	10	5 feet	5 feet	5 feet
Genesee river, about	68	34	39	65
Seneca lake, . .	46	23	62	145
Cayuga lake, . .	6	3	65	195
Rome summit, .	66	33	98	145
Little Falls of Mohawk,	38	19	117	203½ 245½
Schoharie, . .	38	19	136	293½
Height of land between Schenectady & Albany,	24	12	148	220
Hudson's river, .	14	7	155	526
	310			

Casting an eye on the map, it will be seen, that the first difficulty in the above course will be, to cross the Genesee at an elevation of twenty-six feet above its surface. But unless the canal be lowered down to that river, the expense of an aqueduct cannot be avoided; because, from the upper falls, which are too high, there is little descent to the lower falls; and if, from any cause, it be advisable to cross it by an aqueduct, the addition of a foot in height will not much increase the expense:

indeed, considering the swell of the river in freshes, an elevation short of twenty feet would scarcely leave sufficient space under the arch.

The next difficulty will be in crossing the mouth of Seneca lake by an aqueduct eighty-three feet high. But this also, if a convenient place can be found, will not be important, because a moderate aperture will suffice to void the equable stream from that lake.

The third difficulty is at the mouth of Cayuga, where the elevation is one hundred and thirty feet. Even this might be encountered without any unusual hardihood, if the hills approached each other. But the valley to be crossed is not much, if any thing short of a mile; and to erect a mound of that length and of the sufficient height and breadth, is an herculean labour. Whether it will be performed, must depend on the arm that undertakes this task, respecting which, a few words may find their proper place hereafter.

Supposing, however, that difficulty to be surmounted, it is believed that none will remain which cannot be, in a considerable degree, avoided by bending occasionally to the southward, and returning round the northern points of the hills, till the canal is brought opposite to Rome. Its elevation there above the Mohawk will be forty-seven feet, or less, by one foot for every two miles that it may be lengthened. The general face of the country here leaves no room to doubt that convenient ground can be discovered south of Rome, at an elevation of forty feet above the Mohawk. How far it may be practicable between that place and the hills east of the Schoharie, must be decided by actual survey.

The elevation, if not in other respects injurious, will be useful in passes that might otherwise necessitate a descent to the Mohawk. Thus, at the Little Falls at that river, the canal, at an elevation of eighty feet above its upper surface, may, it is believed, be brought through or round the hill at no enormous expense. The still greater elevation of one hundred and fifty feet at the Schoharie, will permit of a considerable bend to find some narrow gorge, and finally an elevation of seventy feet above the height of ground between Schenectady and Albany, will enable the engineer to choose, for the course of his canal and the position of his locks, the most suitable soil and convenient situations. In a word, if, on due examination, any thing of this sort should be found practicable, instead of depriving the country of water, every drop of which is needed by its inhabitants, they will gain a great addition from the canal; and as to the navigation, singly considered, there can be no doubt but it must in that way be superior to a waving course ascending and descending by locks. For, not to mention the expense of constructing and keeping them in repair, the time spent and tolls paid in passing them, must considerably enhance the freight of goods. But if there be no lockage, and the toll be no more than is needful to keep the canal in repair, it will amount to so little, as not to merit notice in a calculation of freight. Rejecting it, therefore, and allowing two horses and three men to take a boat of fifty tons burden, twenty miles a day, which is certainly within bounds, and putting the whole expense at five dollars on the lading, downward, (leaving the return load as profit,) or, which is equivalent, reducing the distance one half, we have fifty tons transported ten miles for five dollars, being one cent per ton per mile. To speak then, in round numbers, it will cost three dollars to bring a ton from lake Erie to Hudson's river, being litttle more than one half of what is now paid for freight on lake Ontario, between Oswego and Lewiston. Without entering into calculations (which every person can easily make for himself) to enumerate the bulky articles which will derive value from such facility of transportation, it may be proper in this place to recur again to the commercial competition with our British neighbours.

A tolerable good navigation up and down the St. Lawrence already exists; but the cheapest rate at which transportation has been performed within the last ten years between Kingston and Montreal, according to the best information the commissioners have been able to obtain, is one dollar per hundred, ascending, and half as much descending the river. But admitting the freight could be so reduced as to be on a level with that between Albany and New-York; admitting, also, that the transportation across lake Ontario could be performed as cheaply as through the proposed canal, and even admitting that the risk on that lake, and, of course, the premium of insurance, were nothing; still it would follow, that transportation from the head of lake Ontario to Montreal would cost as much as from the mouth of Tanewanta to New-York, leaving a preference to the latter of the cost of land carriage from Chippeway to Queenstown. Moreover, nature has given (other things being equal) a decided preference to the port of New-York. There are, generally speaking, six weeks of navigation from Albany, in the spring, before vessels can with safety leave Montreal to descend the river St. Lawrence, and as many more in the autumn, after the mouth of that river is closed.

The navigation from New-York is seldom obstructed; so that produce deposited there can be sent to market during five months, in which, at Montreal, it lies a dead weight on the hands of the owner. This circumstance is of especial importance in regard to wheat and flour, which can be sent from New-York so as to be sold in the south of Europe, before those articles can be brought from the Baltic, or gathered in the country: whereas, if shipped from Montreal in the month of May, they cannot reach Spain or Portugal until after supplies are received from Dantzic, and but a short time before the harvest, which is early in July.

Thus, it is evident that the canal will, if properly effected, turn to the United States the commerce of the upper lakes. Moreover, a side cut, of five or six miles, would, by means of locks, connect it with lake Ontario, in the harbour of the Genesee; and in like manner, a connexion would be established with the Seneca and Cayuga lakes, from the heads of which, the short portage by good roads to Newtown and Oswego opens a communication through the Susquehannah to the Chesapeake. Nor is it improbable, that by running up on the west side of the Cayuga, means may be found to establish water communication with the Susquehannah; from the great bend of which a good and short road may be made to the Delaware.

Thus a variety of markets may be opened to stimulate and reward the industry of those who are now, or may be hereafter settled along the great lakes, whose shores, exclusive of lake Superior, are upwards of two thousand miles, surrounded at convenient distance by more than fifty million acres of land.

To the question, What will the proposed canal cost? it is not possible to answer with any thing like precision. Indeed, preliminary points are to be adjusted; and of these, the first is, whether it is to be made for sloops or barges. The expense of the former will be, it is believed, at least double that of the latter. Another question, whether it is to be carried along an inclined plane, or by a line ascending and descending, must be decided by a comparison of the expense and of the utility each way. In general, however, it may be satisfactory to the honourable the senate and assembly, to receive the information which the commissioners feel no hesitation in giving; that, as far as they have been able to extend their inquiry, there is no part of the civilized world, in which an object of such great magnitude can be compassed at so small an expense. Generally speaking, the course is through a tract of country, the excavation whereof will be easy, and there is, at certain convenient distances from the spots where it may be wanted, a sufficiency of freestone as well as of limestone, with a superabundance of fuel. The subsistence of men, also, and of cattle, will be abundant and cheap. The wages of the former are, as is well known, high; but measures may certainly be devised to obtain the labour for so great a public work more cheaply than is practicable in private operations on a small scale. But the commissioners beg leave to observe, that no supposable expense can bear an undue proportion to the value of the work. Thus, were it (by giving a loose to fancy) extended to fifty millions of dollars, even that enormous sum does not exceed half the value of what, in all human probability, and at no distant period, will annually be carried along the canal. The more proper question, perhaps, is, in what time can it be effected; for if an annual sum be appropriated, and secured on a solid fund, it will be effected in time, and the greater the sum, the shorter will be the period.

The commissioners have no doubt but that good bargains for the public may be made with those through whose land the canal shall pass; and they have great pleasure in stating, that generous offers have already been made, by many proprietors, the acceptance of which must necessarily be deferred to the moment when the business, assuming a more substantial form, shall be committed to superintendants duly authorized to treat. Enough has been said to show that no accurate estimate of the expense can as yet be made. To give some general notion, however, it may be assumed, that, in common cases, labourers ought to dig and remove, to a considerable distance, eight cubic yards per day. The excavation may therefore be set at the eighth of a dollar per cubic yard. An average breadth of fifteen yards, and depth of one yard, which, by means of the mound on each side, will be sufficient for four and a half to five feet of water, giving for each yard in length fifteen cubic yards, may therefore be taken at two dollars, and the mile at 3520 dollars: but allowing for the obstructions of trees and roots, not less than 4000 dollars. This gives, for three hundred miles, one million two hundred thousand dollars. The excavation needful to bring a column of water fifteen yards wide, and two yards deep, with sufficient descent from the Tanewanta, through the middle steep, will, at the same rate, cost two hundred and fifty thousand dollars. Thus, to speak in round numbers, the canal, alone, might cost a million and a half, drawn through a favourable soil, lying conveniently, without the opposition of rocks or other impediments. Many of these, however, must be expected, and will, perhaps, double that sum. Another great expense is that of locks and aqueducts. It is said that the former will cost at the rate of one thousand dollars per foot of ascent for a vessel of fifty tons. This is believed to be a low estimate. At any rate, in a canal like the present, there must be a double set; one for the ascending, and one for the descending navigation. Even then it is to be feared there will be much of embarrassment and delay. Thus, the lockage being taken at two thousand dollars per foot, for three hundred and forty feet of descent and ascent, between lake Erie and Rome, will cost six hundred and eighty thousand dollars, should that waving course be deemed advisable. From Rome to Hudson's river, a descent of three hundred and eighty feet, will call for an addition of seven hundred and sixty thousand dollars.

If, then, the locks be put at a million and a half, it is the lowest rate which can prudently be supposed. It would indeed be safer to set them at two millions. There will still remain for aqueducts, embankments and mounds, a considerable expenditure, which cannot at present be ascertained. To estimate the expense of aqueducts, it may be advisable to put the cubic yard of masonry at two dollars, and consider the aqueduct as a solid mass. It is true, that not more, perhaps, than one-third of the materials required for a solid mass will be used; but the workmanship on those materials will be much more costly. Many of the stones must be hewn, and many clamped together with iron. Moreover, the expense, when such buildings are raised to a great height, is proportionately greater than when nearer the earth. An aqueduct over the Genesee may perhaps be one hundred and fifty yards long. But, to avoid mistakes, it will be more advisable to suppose two hundred. The height above-mentioned is twenty-six feet. But, as well to obviate mistakes, as for convenience of calculation, it may be taken as ten yards, and, in order to preserve the full breadth of the canal, the aqueduct may be considered as twenty yards wide. Thus we have a result of forty thousand cubic yards of masonry, which, at two dollars, will require an expenditure of eighty thousand dollars. A remark which will not escape the most cursory observer is, that a single set of locks to ascend and descend five and twenty feet, will cost fifty thousand dollars, at the lowest estimation; and on the system of level canals, the descent in this case is sixty-five feet. Excepting the Genesee, no considerable aqueduct will be needful; because the streams from the lakes being equable, small arches may be turned over them, and the canal be carried along a mound of earth. The expense of such mound must depend on the convenience of obtaining materials. Where hills of sufficient elevation in the neighbourhood give the advantage of running along wooden rail-ways, or where the transportation may be by boats, along the canal itself, a mound will cost but little, compared to that which is raised solely by the labour of men and cattle. All estimates, therefore, which are not founded on exact local knowledge, must be vague and uncertain. Assuming, however, as a basis, the price of one dollar for eight cubic yards; to estimate the expense of a mound over the Cayuga lake, one hundred and thirty feet high, and sixty feet wide, on the top, with an inclination of five and forty degrees, in the descent of the side, we have at the base one hundred and ninety feet, giving a mean width of one hundred and twenty-five; which, multiplied by the height one hundred and thirty, is sixteen thousand two hundred and fifty feet, or, in round numbers, one thousand eight hundred square yards. These, at the eighth of a dollar each cubic yard, will cost, for every yard of the mound in length, two hundred and twenty-five dollars. Allowing, therefore, two thousand yards instead of a mile, so as to compensate for the expense of an arch two hundred feet long, with a span of fifty feet over the stream, and for other contingencies, the whole cost might be four hundred and fifty thousand dollars, perhaps half a million.

Under the impression resulting from these observations, it is believed that one million of dollars would provide for every thing of this sort, so as to bring the canal to a reservoir near Hudson's river, without locks, for four millions of dollars; a descent there, of from three to four hundred feet by locks, would cost, perhaps, another million; or if it should be deemed more advisable to transport by rail-ways, the water used for machinery would probably yield a rent sufficient to keep the canal in repair.

But, hitherto, this navigation has been contemplated no further than to the mouth of Tanewanta, in Niagara river. From thence to lake Erie is ten miles, and the last mile, at Black Rock rapid, is said to have, through part of a fall which is, on the whole, four feet, a rapidity of near seven miles an hour; so that vessels descending below it may wait a whole season for wind sufficiently strong to get up.

This obstacle, though great, does not appear insurmountable. Perhaps two wharves, similar to those which surround our cities, made impervious to the water, and sunk parallel to each other during the distance of one mile, with two pair of gates similar to those of dry docks, placed so as that the upper one being shut, there shall be still water from below, and that the lower one shut, will make still water above, may fully answer the end. The cost, where wood and stone are so abundant, cannot be great; and as wood is not liable to rot under water, nor exposed in fresh water to the ravages of worms, the work may be sufficiently durable. On the whole, it is conceived that the expense of this national work may be five millions of dollars; a sum which does not, it is presumed, exceed five per cent. of the value of the commodities, which, in less than a century, it will annually transport, should it be now commenced, so as duly to encourage population around the upper lakes.

The commissioners hope they shall be excused, if, in this place, they advert to a question more important, perhaps, than any other. By whom shall the needful expense be supported?

They take the liberty of entering their feeble protest against a grant to private persons or companies. Too great a national interest is at stake. It must not become the subject of a job, or a fund for speculation. Among many other objections, there is one insuperable: That it would defeat the contemplated cheapness of transportation. It should always on occasions of this sort be recollected, that the reasons adduced for grants to individuals in Europe apply inversely here. Few of our fellow citizens have more money than they want, and of the many who want, few find facility in obtaining it. But the public can readily, at a fair interest, command any reasonable sum. Moreover, such large expenditures can be more economically made under public authority, than by the care and vigilance of any company.

It remains therefore to determine, whether this canal should be at the cost of this state or of the Union. If the state were not bound by the federal band with her sister states, she might fairly ask compensation from those who own the soil along the great lakes for the permission to cut this canal at their expense; or her statesmen might deem it still more advisable, to make the canal at her own expense, and take for the use of it a transit duty; raising or lowering the impost, as circumstances might direct for her own advantage. This might be the better course, if the state stood alone. But, fortunately for the peace and happiness of all, this is not the case; we are connected by a bond, which, if the prayers of good men are favourably heard, will be indissoluble. It becomes proper, therefore, to resort, for the solution of the present question, to the principles of distributive justice. That which presents itself is the trite adage, that those who participate in the benefit should contribute to the expense.

The commissioners presume not to go one step farther. The offers of individuals, already alluded to, show their conviction of that equity by which the state is called on for her share. The wisdom as well as justice of the national legislature will, no doubt, lead to the exercise on their part of prudent munificence; but the proportion, the conditions, the compact in short, must be the result of treaty. Whether the honourable the senate and assembly will take steps towards a negociation, and what these steps may be, it is in their wisdom to determine.

The gentlemen whose names are subscribed to this report, are Gouv. Morris, S. V. Rensselaer, W. North, De Witt Clinton, Thomas Eddy, Peter B. Porter, Simeon De Witt. It was presented to the legislature in February, 1811.

The entire subsequent execution of the double enterprise, of forming canals from the Hudson river in one direction to lake Erie, and on the other to lake Champlain, though departing in some details, has, however, in a considerable degree followed the suggestions of this report. As the design, and in some measure the performance of the Erie canal were prior to the plan and execution of that of Champlain, we first turn our attention to the former.

The object of the Erie canal is, to effect a slack water navigation from the head of sloop navigation in the Hudson into lake Erie. To have any adequate idea of such a work when completed, it is necessary to possess a clear view of the geography of the ground over which it must pass; we shall therefore, in reviewing the subject, endeavour to combine a succinct history of the advance of the enterprise, a topographical survey of the ground, with an analysis of the work itself, commencing at the head of sloop navigation at Albany, and advancing towards lake Erie.

The intermediate period which elapsed from the passage of the act of the legislature of New York, on the 8th of April 1810, until the close of the last war between the United States and Great Britain, was in a peculiar degree unpropitious to the execution of such a work as that of a canal, from the Hudson river to the central parts of the Canadian sea, or into lake Erie. But, if unfavourable to the prosecution of so magnificent a plan, the intervening events were in a high degree calculated to exhibit the necessity, and to stimulate to the formation of such a chain of water communication.

The adverse aspect of the times did not deter the commissioners under the act of 1811 from proceeding, as far as in their power, to give efficiency to the provisions of that law. In March 1812, they made their report, in which they stated to the legislature of New-York the following facts.

That in obedience to the directions of that act they had made application to the general government, by a letter to the President of the United States, and an application to the Senate and House of Representatives. Gouverneur Morris, and De Witt Clinton, were the deputies who made the application to the general government, which ended in obtaining neither assistance nor encouragement.

The commissioners, at the same time with their mission to the general government, addressed several of the individual states on the same subject, and received replies from Tennessee, New-Jersey, Connecticut, Vermont, Massachusetts, Ohio, and Michigan territory. The legislature of Tennessee directed their senators and representatives in Congress, to support "any laudable attempt, made to the Congress of the United States, soliciting the aid of the general government, in relation to the canal navigation between Hudson's river and the great lakes." The legislature of New-Jersey expressed approbation of the plan, but for various reasons declined yielding any direct aid to forward its performance. The legislature of Connecticut deemed any proceeding on the application of the New-York commissioners inexpedient, and, expressing full confidence in their representatives in Congress, left their views on the subject discretionary. The legislature of Vermont acknowledged the importance of the subject, but, having received the application of the commissioners too late in the session, declined taking any measures, pleading want of time as an excuse. The legislature of Massachusetts very warmly approved the canal project, and resolved unanimously, "that the senators of that commonwealth should be instructed to use their influence for promoting, by all reasonable encouragement, (in such mode as Congress in their wisdom might direct,) the opening of a communication, by means of a canal navigation, between the great lakes and Hudson's river,* regard being had to the special benefit which would accrue to the state of New-York, from the accomplishment of that project." The Governor, Judges, &c. of Michigan, disagreed with the policy of the projected route of a canal, direct from the head of the Mohawk river to lake Erie, but preferred canals and locks between Erie and Ontario lakes, and between the latter and Oneida lake round the falls of Oswego river.

The legislature of Ohio fully opposed the plan, in all its outline and details.

The commissioners recite these facts, and proceed to ably develope the superior advantages and practicability of the inland route from the Mohawk, by Seneca river, to lake Erie, over that by Oneida lake, Oswego river, lake Ontario, and Niagara river.*

They then proceed to show the benefits which, in a commercial and political point of view, must arise from the contemplated canal. They examine the probable expenses necessary for its execution, and the resources of the state to meet such an expenditure, and conclude their estimate with avowing their opinion, that funds adequate to the full accomplishment of the design are completely within reach of the state of New-York.

This report closes by simply hinting at the northern route from the Hudson to lake Champlain, towards the opening of which at that period no steps had been taken.

The commissioners who made this masterly communication to the legislature were, Gouverneur Morris, S. V. Renssalaer, De Witt Clinton, Simeon De Witt, William North, Thomas Eddy, and Robert R. Livingston.†

From the date of the foregoing report two years passed away, during the war with Great Britain, in which inland improvement was overlooked, and the attention of the public drawn to national defence. When, however, men of luminous minds have fully investigated the practicability of any plan, weighed its advantages, and staked their reputation on its execution, it is no slight difficulty which can divert their minds from seeking every laudable means to procure success. Death has placed his sacred seal upon the fame of Robert Fulton, and rendered venerable every document to which his hand was placed. Similar observations may be made upon the name and character of the ardent Gouverneur Morris; he also is gone beyond the reach of human suspicion. These two truly great men were amongst those who again, on the 8th of March, 1814, roused the people of New-York to an attention to their own interest, and to a resumption of the plan to effect the Erie canal; their coadjutors were, S. V. Renssalaer, De Witt Clinton, Simeon De Witt, Peter B. Porter, and Thomas Eddy.

From this report it appears, that at its date no ostensive step had been taken to even survey the canal route. No engineer had been employed, though application had been made for one from Great Britain, which had been rendered abortive by the events of the war, and its continuance. The tenor of the report shows, however, that the original promoters of the canal design still remained active, and used every means within their reach to collect accurate information respecting the intermediate country, and they again allude to the practicability of a canal between Hudson's river and lake Champlain. The commissioners once more controvert forcibly the supposed superiority and practicability of the Ontario route over that proposed. Some large proffered grants of land by individuals and agents are stated. It would be of little use to name the grantors, as none or very trifling aid has been ever given in that manner to the actual execution of the New-York canals.

The project of procuring a loan of money in Europe, and the causes of its abortive issue, is made known to the legislature by the commissioners, which is followed by some severe reflections upon the opponents of the canal policy, couched in well expressed terms of bitter sarcasm. The report closes with an extract of a letter from William Weston, English engineer, containing the following sublime expressions, which could only have flown from a mind of the first order, and could only be inspired by the contemplation of a great design.

"Should your noble, but stupendous plan of uniting lake Erie with the Hudson, be carried into effect, you have to fear no rivalry. The commerce of the immense extent of country, bordering on the upper lakes, is your's for ever, and to such an incalculable amount, as would baffle all conjecture to conceive. Its execution would confer immortal honour on the projectors and supporters, and would, in its eventual consequences, render New York the greatest commercial emporium in the world, with perhaps the exception, at some distant day, of New-Orleans, or some other depot, at the mouth of the majestic Mississippi. From your perspicuous topographical description, and neat plan and profile of the route of the contemplated canal, I entertain little doubt of the practicability of the measure. Perhaps this is the only question which the legislature should be particularly anxious to have resolved. The expense, be it what it may, is no object, when compared with the incalculable benefits arising therefrom, though, doubtless, it will deserve attention, that the money granted liberally, be wisely and economically expended."*

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* Haines, on the commencement and progress of New-York canals, p. 39.

† Haines, p. 35—55.

From the date of the foregoing report, two years again elapsed before any effective measures were adopted by the legislature of New York, in respect to the contemplated canals: but in March, 1816, that masterly memorial of the citizens of New-York to the Legislature was presented, which led to the passage of the act of 1816, and eventually to the commencement, by New York alone, of one of the greatest works of modern ages.

So much of topographical information and of accurate knowledge of the relations of inland navigation in the United States is contained in the memorial alluded to, that we have deemed it necessary to lay before our readers all those parts particularly applicable to New York, and the contiguous states. The Commissioners state:

It is calculated that the expense of transporting on a canal amounts to one cent a ton per mile, or one dollar a ton for one hundred miles; while the usual cost by land conveyance is one dollar and sixty cents per hundred weight, or thirty-two dollars a ton for the same distance. The celerity and certainty of this mode of transportation are evident. A loaded boat can be towed by one or two horses, at the rate of thirty miles a day. Hence the seller or buyer can calculate with sufficient precision on his sales or purchases, the period of their arrival, the amount of their avails, and the extent of their value. A vessel on a canal is independent of winds, tides, and currents, and is not exposed to the delays attending conveyances by land: and with regard to safety there can be no competition. The injuries to which commodities are exposed when transported by land, and the dangers to which they are liable when conveyed by natural waters, are rarely experienced on canals. In the latter way, comparatively speaking, no waste is incurred, no risk is encountered, and no insurance is required. Hence, it follows, that canals operate upon the general interests of society in the same way that machines for saving labour do in manufactures; they enable the farmer, the mechanic, and the merchant, to convey their commodities to market, and to receive a return at least thirty times cheaper than by roads. As to all the purposes of beneficial communication, they diminish the distance between places, and therefore encourage the cultivation of the most extensive and remote parts of the country. They create new sources of internal trade, and augment the old channels; for, the more cheap the transportation, the more expanded will be its operation, and the greater the mass of the products of the country for sale, the greater will be the commercial exchange of returning merchandise, and the greater the encouragement to manufacturers, by the increased economy and comfort of living, together with the cheapness and abundance of raw materials; and canals are consequently advantageous to towns and villages, by destroying the monopoly of the adjacent country, and advantageous to the whole country; for though some rival commodities may be introduced into the old markets, yet many new markets will be opened, by increasing population, enlarging old and erecting new towns, augmenting individual and aggregate wealth, and extending foreign commerce.

The general arguments in favour of inland navigation apply with peculiar force to the United States, and most emphatically to this state, (New-York.) A geographical view of the country will at once demonstrate the unexampled prosperity, that will arise from our cultivating the advantages which Nature has dispensed with so liberal a hand. A great chain of mountains passes through the United States, and divides them into eastern and western America. In various places, rivers break through those mountains, and are finally discharged into the ocean. To the west, there is a collection of inland lakes, exceeding, in its aggregate extent, some of the most celebrated seas of the old world. Atlantic America, on account of the priority of its settlement, its vicinity to the ocean, and its favourable position for commerce, has many advantages. The western country, however, has a decided superiority in the fertility of its soil, the benignity of its climate, and the extent of its territory. To connect these great sections by inland navigation, to unite our Mediterranean seas with the ocean, is evidently an object of the first importance to the general prosperity. Nature has effected this in some measure; the St. Lawrence emanates from the lakes, and discharges itself into the ocean in a foreign territory. Some of the streams which flow into the Mississippi originate near the great lakes, and pass round the chain of mountains. Some of the waters of this state, which pass into lake Ontario, approach the Mohawk; but our Hudson has decided advantages. It affords a tide navigation for vessels of 80 tons to Albany and Troy, 160 miles above New-York, and this peculiarity distinguishes it from all the other bays and rivers in the United States, viz.

The tide in no other ascends higher than the granite ridge, or within thirty miles of the Blue ridge, or eastern chain of mountains. In the Hudson it breaks through the Blue ridge, and ascends above the eastern termination of the Catskill, or great western chain; and there are no interposing mountains to prevent a communication between it and the great western lakes.

The importance of the Hudson river to the old settled parts of the state, may be observed in the immense wealth which is daily borne on its waters, in the flourishing villages and cities on its banks, and in the opulence and prosperity of all the country connected with it, either remotely or immediately. It may also be readily conceived, if we only suppose, that by some awful physical calamity, some overwhelming convulsion of Nature, this great river was exhausted of its waters: where then would be the abundance of our markets, the prosperity of our farmers, the wealth of our merchants? Our villages would become deserted; our flourishing cities would be converted into masses of mouldering ruins, and this state would be precipitated into poverty and insignificance. If a river, or natural canal, navigable about 170 miles, has been productive of such signal benefits, what blessings might not be expected, if it were extended 300 miles, through the most fertile country in the universe, and united with the great seas of the west! The contemplated canal would be this extension, and viewed in reference only to the productions and consumptions of the state, would perhaps convey more riches on its waters than any other canal in the world. Connected with the Hudson it might be considered as a navigable stream that extends 450 miles through a fruitful country, embracing a great population, and abounding with all the productions of industry: if we were to suppose all the canals of England and Wales combined into one, and discharged into the ocean at a great city, after passing through the heart of that country, then we can form a distinct idea of the importance of the projected canal; but it indeed comprehends within its influence a greater extent of territory, which will in time embrace a greater population. If this work be so important, when we confine our views to this state alone, how unspeakably beneficial must it appear, when we extend our contemplations to the great lakes, and the country affiliated with them! Waters extending two thousand miles from the beginning of the canal, and a country containing more territory than all Great Britain and Ireland, and at least as much as France.

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* Haines, p. 71-76, and 91.

While we not pretend that all the trade of our western world will centre in any given place, (nor indeed would it be desirable if it were practicable, because we sincerely wish the prosperity of all the states,) yet we contend that our natural advantages are so transcendent, that it is in our power to obtain the greater part, and put successful competition at defiance. As all the other communications are impeded by mountains, the only formidable rivals of New-York, for this great prize, are New-Orleans and Montreal, the former relying on the Mississippi, and the latter on the St. Lawrence.

In considering this subject, we will suppose the commencement of the canal somewhere near the outlet of lake Erie.

The inducements for preferring one market to another involve a variety of considerations: the principal are, the cheapness and facility of transportation, and the goodness of the market. If a cultivator or manufacturer can convey his commodities with the same ease and expedition to New-York, and obtain a higher price for them than at Montreal or New-Orleans, and at the same time supply himself at a cheaper rate with such articles as he may want in return, he will undoubtedly prefer New-York. It ought also to be distinctly understood, that a difference in price may be equalized by a difference in the expense of conveyance, and that the vicinity of the market is at all times a consideration of great importance.

From Buffalo, at or near the supposed commencement of the canal, it is 450 miles to the city of New-York, and from that city to the ocean, 20 miles. From Buffalo to Montreal 350 miles; from Montreal to the chops of the St. Lawrence, 450. From Buffalo to New-Orleans by the great lakes, and the Illinois river, 2 250 miles; from New-Orleans to the Gulf of Mexico 100. Hence, the distance from Buffalo to the ocean by the way of New-York, is 470 miles; by Montreal 800: and by New-Orleans 2,350.

As the upper lakes have no important outlet but into lake Erie, we are warranted in saying, that all their trade must be auxiliary to its trade, and that a favourable communication by water from Buffalo will render New York the great depot and warehouse of the western world.

In order, however, to obviate all objections that may be raised against the place of comparison, let us take three other positions, *Chicago*, near the south-west, and of lake Michigan, and a creek of that name, which sometimes communicates with the Illinois, the nearest river from the lakes to the Mississippi: *Detroit*, on the river of that name, between lakes St. Clair and Erie; and *Pittsburgh*, at the confluence of the Alleghany and Monongahela rivers, forming the head of the Ohio, and communicating with Le Beuf by water, which is distant fifteen miles from lake Erie.

The distance from Chicago to the ocean by New-York, is about 1,200 miles. To the mouth of the Mississippi, by New Orleans, near 1,600 miles, and to the mouth of the St. Lawrence, by Montreal, near 1,600 miles.

The distance from Detroit to the ocean by New-York, is near 700 miles. From Detroit to the ocean by Montreal, is 1,050 miles. From Detroit to the ocean, pursuing the nearest route by Cleveland, and down the Muskingum, 2,400 miles. The distance from Pittsburgh to the ocean, by Le Beuf, lake Buffalo, and New-York, is 700 miles. The same to the ocean by Buffalo and Montreal, 1,050 miles. The same to the ocean by the Ohio and Mississippi, 2,150 miles.

These different comparative views show that New-York has, in every instance, a decided advantage over her great rivals. In other essential respects the scale preponderates equally in her favour. Supposing a perfect equality of advantages as to the navigation of the lakes, yet from Buffalo, as the point of departure, there is no comparison of benefits. From that place the voyager to Montreal has to encounter the inconveniences of a portage at the cataract of Niagara, to load and unload at least three times, to brave the tempests of lake Ontario and the rapids of the St. Lawrence.

In like manner, the voyager to New-Orleans has a portage between the Chicago and Illinois, an inconvenient navigation on the latter stream, besides the well-known obstacles and hazards of the Mississippi. And until the invention of steam-boats, an ascending navigation was considered almost impracticable. This inconvenience is, however, still forcibly experienced on that river, as well as on the St. Lawrence, between Montreal and lake Ontario.

The navigation from lake Erie to Albany can be completed in ten days with perfect safety on the canal; and from Albany to New-York there is the best sloop navigation in the world.

From Buffalo to Albany, a ton of commodities could be conveyed, on the intended canal, for three dollars, and from Albany to New-York, according to the present prices of sloop transportation, for \$$2\frac{80}{100}$, and the return cargoes would be the same.

We have not sufficient data upon which to predicate very accurate estimates with regard to Montreal and New-Orleans; but we have no hesitation in saying, that the descending conveyance to the former would be four times the expense, and to the latter at least ten times, and that the cost of the ascending transportation would be greatly enhanced.

It has been stated by several of the most respectable citizens of Ohio, that the present expense of transportation by water from the city of New-York to Sandusky, including the carrying places, is \$$4\frac{50}{100}$ per hundred, and allowing it to cost two dollars per hundred for transportation to Clinton, the geographical centre of the state, the whole expense would be \$$6\frac{50}{100}$, which is only fifty cents more than the transportation from Philadelphia to Pittsburgh, and at least $\$2\frac{50}{100}$ less than the transportation by land and water from these places, and that, in their opinion, New-York is the natural emporium of that trade, and that the whole commercial intercourse of the western country north of the Ohio, will be secured to her by the contemplated canal.

In addition to this, it may be stated, that the St. Lawrence is generally locked up by ice seven months in the year, during which time produce lies a dead weight on the hands of the owner; that the navigation from New-York to the ocean is at all times easy, and seldom obstructed by ice, and that the passage from the Balize to New-orleans is tedious; that perhaps one out of five of the western boatmen who descend the Mississippi, become victims to disease; and that many important articles of western production are injured or destroyed by the climate. New-York is, therefore, placed in a happy medium between the insalubrious heat of the Mississippi, and the severe cold of the St. Lawrence. She has also pre-eminent advantages, as to the goodness and extensiveness of her market. All the productions of the soil and the fabrics of art can command an adequate price, and foreign commodities can generally be procured at a lower rate. The trade of the Mississippi is already in the hands of her merchants, and although accidental and transient causes may have concurred to give Montreal an ascendancy in some points, yet the superiority of New-York is founded in nature, and if improved by the wisdom of government, must always soar above competition.

Granting, however, that the rivals of New-York will command a considerable portion of the western trade, yet it must be obvious, from these united considerations, that she will engross more than sufficient to render her the greatest commercial city in the world. The whole line of canal will exhibit boats loaded with flour, beef, pot and pearl ashes, flaxseed, wheat, barley, corn, hemp, wool, flax, iron, lead, copper, salt, gypsum, coal, tar, fur, peltry, ginseng, bees-wax, cheese, butter. lard, staves, lumber, and the other valuable productions of our country; and also with merchandise from all parts of the world. Great manufacturing establishments will spring up; agriculture will establish its granaries, and commerce its warehouses in all directions. Villages, towns, and cities, will line the banks of the canal, and the shores of the Hudson from Erie to New-York. 'The wilderness and the solitary place will become glad, and the desert will rejoice and blossom as the rose.'

While it is universally admitted that there ought to be a water communication between the great lakes and the tide waters of the Hudson, a contrariety of opinion, (greatly to be deplored, as tending to injure the whole undertaking) has arisen with respect to the route that ought to be adopted. It is contended on the one side, that the canal should commence in the vicinity of the outlet of lake Erie, and be carried in the most eligible direction across the country to the head-waters of the Mohawk river at Rome: from whence it should be continued along the valley of the Mohawk to the Hudson. It is, on the other side, insisted, that it should be cut round the cataract of Niagara; that lake Ontario should be navigated to the mouth of the Oswego river; that the navigation of that river and Wood creek should be improved and pursued until the junction of the latter with the Mohawk at Rome. As to the expediency of a canal from Rome to the Hudson, there is no discrepance of opinion: the route from Rome to the great lakes constitutes the subject of controversy.

If both plans were presented to the Legislature, as worthy of patronage, and if the advocates of the route by lake Ontario did not insist that their schemes should be exclusive, and, of course, that its adoption should prove fatal to the other project, this question would not exhibit so serious an aspect. If two roads are made, that which is most accommodating will be preferred; but if only one is established, whether convenient or inconvenient to individuals, beneficial or detrimental to the public, it must necessarily be used. We are so fully persuaded of the superiority of the Erie canal, that, although we should greatly regret so useless an expenditure of public money as making a canal round the cataract of Niagara, yet we should not apprehend any danger from the competition of Montreal, if the former were established.

An invincible argument in favour of the Erie canal is, that it would diffuse the blessings of internal navigation over the most fertile and populous parts of the state, and supply the whole community with salt, gypsum, and, in all probability, coal. Whereas, the Ontario route would accommodate but an inconsiderable part of our territory, and instead of being a great highway, leading directly to the object, it would be a circuitous by-road, inconvenient in all essential respects.

The most serious objection against the Ontario route is, that it will inevitably enrich the territory of a foreign power, at the expense of the United States. If a canal is cut round the falls of Niagara, and no countervailing nor counteracting system is adopted in relation to lake Erie, the commerce of the west is lost to us for ever. When a vessel once descends into Ontario, she will pursue the course ordained by nature. The British government are fully aware of this, and are now taking the most active measures to facilitate the passage down the St. Lawrence.

It is not to be concealed, that a great portion of the productions of our western country are now transported to Montreal, even with all the inconveniences attending the navigation down the Seneca and Oswego rivers; but if this route is improved, in the way proposed, and the other not opened, the consequences will be most prejudicial. A barrel of flour is now transported from Cayuga lake to Montreal for $\$1\frac{50}{100}$ and it cannot be conveyed to Albany for less than $\$2\frac{50}{100}$. This simple fact speaks a volume of admonitory instruction.

But taking it for granted, that the Ontario route will bring the commerce of the west to New-York, yet the other ought to be preferred, on account of the superior facilities it affords.

In the first place, it is nearer. The distance from Buffalo to Rome is less than 200 miles in the course of the intended canal: by lake Ontario and Oswego, it is 232.

2. A loaded boat could pass from Buffalo to Rome by the Erie route in less than seven days, and with entire safety. By the Ontario route, it will be perfectly uncertain, and not a little hazardous. After leaving the Niagara river, it would have to pass an inland sea to the extent of 127 miles, as boisterous and as dangerous as the Atlantic. And besides a navigation of at least twenty miles over another lake, it would have to ascend two difficult streams for 55 miles; no calculation could then be made, either on the certainty or safety of this complicated and inconvenient navigation.

3. When a lake vessel would arrive at Buffalo, she would have to unload her cargo, and when this cargo arrived at Albany by the Erie canal, it would be shifted on board of a river sloop, in order to be transported to

New-York. From the time of the first loading on the great lakes, to the last unloading at the store-houses in New-York, there would be three loadings and three unloadings on this route.

But when a lake vessel arrived with a view of passing the canal of Niagara, she would be obliged to shift her lading for that purpose, for it would be almost impracticable to use lake vessels on the Niagara river, on account of the difficulty of the ascending navigation. At Lewistown, or some other place on the Niagara, another change of the cargo on board of a lake vessel for Ontario, would be necessary; at Oswego another, and at Albany another; so that on this route there would be five loadings, and five unloadings, before the commodities were stored in New-York.

This difference is an object of great consequence, and presents the most powerful objections against the Ontario route; for to the delay we must add the accumulated expense of these changes of the cargo, the storage, the waste, and damage, especially by theft, (where the chances of depredation are increased by the merchandise passing through a multitude of hands) and the additional lake vessels, boats, and men that will be required, thereby increasing, in this respect alone, the cost two-thirds above that attending the other course. And, in general, it may be observed, that the difference between a single and double freight forms an immense saving. Goods are brought from Europe for twenty cents per cubic foot; whereas the price from Philadelphia to Baltimore is equal to ten cents. This shows how far articles, once embarked, are conveyed with a very small addition of freight; and if such is the difference between a single and a double freight, how much greater must it be in the case under consideration!

If the fall from lake Erie to lake Ontario be 450 feet, as stated in Mr. secretary Gallatin's report on canals, it will require at least forty-five locks for a navigation round the cataract. Whether it would be practicable to accommodate all the vessels which the population and opulence of future times will create in those waters, with a passage through so many locks accumulated within a short distance, is a question well worthy of serious consideration. At all events, the demurrage must be frequent, vexatious, and expensive.

When we consider the immense expense which would attend the canal proposed on the Niagara river; a canal requiring so many locks, and passing through such difficult ground; when we view the Oswego river, from its outlet at Oswego, to its origin in Oneida lake, encumbered with dangerous rapids and falls, and flowing through a country almost impervious to canal operations; and when we contemplate the numerous embarrassments which are combined with the improvement of Wood creek; we are prepared to believe that the expense of this route will not greatly fall short of the other.

It is however alleged, that it is not practicable to make this canal; and that, if practicable, the expense will be enormous, and will far transcend the faculties of the state.

Lake Erie is elevated 541 feet above the tide waters at Troy. The only higher ground between it and the Hudson is but a few miles from the lake: and this difficulty can be easily surmounted by deep cutting; of course, no tunnel will be required. The rivers which cross the line of the canal can be easily passed by aqueducts; on every summit level, plenty of water can be obtained; whenever there is a great rise or descent, locks can be erected, and the whole line will not require more than sixty-two; perhaps there is not an equal extent of country in the world, which presents fewer obstacles to the establishment of a canal. The liberality of Nature has created the great ducts and arteries, and the ingenuity of art can easily provide the connecting veins. The general physiognomy of the country is champaign, and exhibits abundance of water: a gentle rising from the Hudson to the lake; a soil well adapted for such operations; no impassable hills, and no insurmountable waters. As to distance, it is not to be considered in relation to practicability. If a canal can be made for fifty miles, it can be made for three hundred, provided there is no essential variance in the face of the country; the only difference will be, that, in the latter case, it will take more time, and consume more money.

But this opinion does not rest for its support upon mere speculation. Canals have been successfully cut through more embarrassing ground, in various parts of the United States; and even in part of the intended route from Schenectady to Rome, locks have been erected at the Little Falls, and at other places; and short canals have been made, and all these operations have taken place in the most difficult parts of the whole course of the contemplated Erie navigation. Mr. William Weston, one of the most celebrated civil engineers in Europe, who has superintended canals in this state and Pennsylvania, and who is perfectly well acquainted with the country, has thus expressed his opinion on this subject: "Should your noble but stupendous plan of uniting lake Erie with the Hudson be carried into effect, you have to fear no rivalry. The commerce of the immense extent of country bordering on the upper lakes is yours for ever, and to such an incalculable amount, as would baffle all conjecture to conceive. Its execution would confer immortal honour on the projectors and supporters, and would, in its eventual consequences, render New-York the greatest commercial emporium in the world, with, perhaps, the exception, at some distant day, of New-Orleans, or some other depot at the mouth of the majestic Mississippi. From your perspicuous topographical description, and neat plan and profile of the route of the contemplated canal, I entertain little doubt of the practicability of the measure."*

With regard to the expense of this work, different estimates will be formed. The commissioners appointed for that purpose were of opinion, that it would not cost more than five millions of dollars. On this subject we must be guided by the light which experience affords in analagous cases.

The canal of Languedoc, or canal of the two seas, in France, connects the Mediterranean and the Atlantic, and is 180 miles in length: it has 114 locks and sluices, and a tunnel 720 feet long. The breadth of the canal is 144 feet, and its depth 6 feet: it was begun in 1666, and finished in 1681, and cost 540,000*l.* sterling, or 3,000*l.* sterling a mile.

The Holstein canal, begun in 1777, and finished in 1785, extends about fifty miles: is 100 feet wide at the top, and 54 at the bottom, and not less than 10 feet deep in any part. Ships drawing nine feet four inches water pass through it from the German Ocean, in the vicinity of Tonningen, into the Baltic. From two to three thousand ships have passed in one year. The expense of the whole work was a little more than a million and a half of dollars, which would be at the rate of 30,000 dollars a mile for this ship navigation.

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* Haines, p. 76 and 91.

The extreme length of the canal from the Forth to the Clyde, in Scotland, is 35 miles. It rises and falls 160 feet, by means of 39 locks. Vessels pass drawing eight feet water, having 19 feet beam, and 73 feet length. The cost is calculated at 200,000*l.* sterling, which is at the rate of about 23,000 dollars a mile. But this was a canal for ships drawing eight feet of water, with an extraordinary rise for its length, and having more than one lock for every mile.

The following will give an idea of the money expended on such works in England:

	Cost.	Miles.
The Rochdale canal, - - -	291,900*l.*	31½
Ellesmere, - - - - - - -	400,000	57
Kennet and Avon, - - - -	420,000	78
Grand Junction, - - - -	500,000	90
Leeds and Liverpool, - - -	800,000	129

The miles of canal are 385½, and the cost is 2,411,900*l.* sterling, or about 28,000 dollars per mile.

But in the estimation of the cost of these canals, unquestionably the price of the land over which they pass is included, and this is enormous. The land alone for one canal of 16 miles, is said to have cost 90,000*l.* sterling. With us this would be but small.

If we look at the history of the English canals, we shall see how many objects of great expense are connected with them, with which we should have nothing to do, and that most of them have encountered and surmounted obstacles which we should not meet with. For instance, the Grand Junction canal passes, more than once, the great ridge which divides the waters of England; ours will pass over a country which, in comparison, is champaign.

But it is said that the price of labour in our country is so much above what it is in England, that we must add greatly to the cost of her canals, in estimating the expense of ours. But that is certainly a false conclusion, for not only must the price of the land, and the adventitious objects which have been before referred to, be deducted from the cost of the foreign canals, but we must consider that there will be almost as great a difference in our favour in the cost of materials, and brute labour, as there is in favour of England, as to human labour; and it is well known that so much human labour is not now required on canals as formerly. Machines for facilitating excavation have been invented, and used with great success.

Mr. Gallatin's report on canals contains several estimates of the cost of contemplated ones. From Weymouth to Taunton, in Massachusetts, the expense of a canal of 26 miles, with a lockage of 260 feet, is set down at 1,250,000 dollars. From Brunswick to Trenton, 28 miles, with a lockage of 100 feet, 800,000 dollars. From Christiana to Elk, 22 miles, with a lockage of 148 feet, 750,000 dollars. From Elizabeth river to Pasquotank, 22 miles, with a lockage of 40 feet, 250,000 dollars. These estimates thus vary from 48,000 to less than 12,000 dollars a mile, and furnish the medium of about 31,000 dollars a mile. But it must be observed that they are for small distances, are calculated to surmount particular obstacles, and contemplate an extraordinary number of locks; and that they do not therefore furnish proper data from which to form correct conclusions, with respect to the probable cost of an extensive canal, sometimes running over a great number of miles upon a level, without any expense for lockage, or any other expense than the mere earth work.

Mr. Weston, before mentioned, estimated the expense of a canal, from the tide waters at Troy to lake Ontario, a distance of 160 miles, (exclusive of lake Oneida,) going round the Cohoes, and embracing 55 locks, of eight feet lift each, at 2,200,000 dollars, a little more than 13,000 dollars a mile.

Fortunately, however, we have more accurate information than mere estimates.

In the appendix to Mr. Gallatin's report, it is stated by Mr. Joshua Gilpin, that, "by actual measurement, and the sums paid on the feeder, it was found that one mile on the Delaware and Chesapeake canal, the most difficult of all others, from its being nearly altogether formed through hard rocky ground, cost 13,000 dollars, and one other mile, perfectly level, and without particular impediments, cost 2,300 dollars; from hence, the general average would be reduced to 7,650 dollars per mile."

The Middlesex canal, in Massachusetts, runs over twenty-eight miles of ground, presenting obstacles much greater than can be expected on the route we propose. This canal cost 478,000 dollars, which is about 17,000 dollars a mile. It contains 22 locks of solid masonry, and excellent workmanship, and, to accomplish this work, it was necessary to dig in some places to the depth of 20 feet, to cut through ledges of rocks, to fill some valleys and morasses, and to throw several aqueducts across the intervening rivers. One of these, across the river Shawshine, is 280 feet long, and 22 feet above the river.

From the Tanewanta creek, to the Seneca river, is a fall of, - - - - - - - - - - -	195 feet
From thence to the Rome summit is a rise of	50
From thence to the Hudson river is a fall of	380
The whole rise and fall, - - - - - - -	625 feet.

This will require 62 locks of ten feet lift each. The expense of such locks, as experimentally proved in several instances in this state, would be about 620,000 dollars.

We have seen, that on the Middlesex canal there are 22 locks for 28 miles, which is a lock for somewhat more than every mile, whereas 62 locks for 300 miles is but about one lock for every five miles; and the lockage of the Middlesex canal would alone cost 220,000 dollars. It would, therefore, appear to be an allowance perhaps too liberal, to consider the cost of it as a fair criterion of the expense of canals in general in this country, and of this in particular. Reservoirs and tunnels are the most expensive part of the operation, and none will be necessary in our whole route. The expense of the whole earth work of excavating a mile of canal on level ground fifty feet wide and five feet deep, at 18 cents per cubic yard, and allowing for the cost of forming and trimming the banks, puddling, &c. will not exceed 4000 dollars per mile, and the only considerable aqueduct on the whole line will be over the Genesee river.

From a deliberate consideration of these different estimates and actual expenditures, we are fully persuaded that this great work will not cost more than 20,000 dollars a mile, or six millions of dollars in the whole; but willing to make every possible allowance, and even conceding that it will cost double that sum, yet still we contend that there is nothing which ought to retard its execution. This canal cannot be made in a short time. It will be the work perhaps of 10 or 15 years.

The money will not be wanted at once. The expenditure, in order to be beneficial, ought not to exceed 500,000 dollars a year, and the work may be accomplished in two ways; either by companies, incorporated for particular sections of the route, or by the state. If the first is resorted to, pecuniary sacrifices will still be necessary on the part of the public, and great care ought to be taken to guard against the high tolls, which will certainly injure, if not ruin the whole enterprise.

If the state shall see fit to achieve this great work, there can be no difficulty in providing funds. Stock can be created and sold at an advanced price. The ways and means of paying the interest will be only required. After the first year, supposing an annual expenditure of 500,000 dollars, thirty thousand dollars must be raised to pay an interest of six per cent; after the second year 60,000, and so on. At this rate of interest they will regularly increase with beneficial appropriation, and will be so little in amount that it may be raised in many shapes without being burdensome to the community. In all human probability, the augmented revenue proceeding from the public salt works, and the increased price of the state lands, in consequence of this undertaking, will more than extinguish the interest of the debt contracted for that purpose. We should also take into view, the land already subscribed by individuals for this work, amounting to 106,632 acres. These donations, together with those which may be confidently anticipated, will exceed in value a million of dollars, and it will be at all times in the power of the state to raise a revenue from the imposition of transit duties, which may be so light as scarcely to be felt, and yet the income may be so great as in a short time to extinguish the debt, and this might take effect on the completion of every important section of the work.

If the legislature shall consider this important project in the same point of view, and shall unite with us in opinion, that the general prosperity is intimately and essentially involved in its prosecution, we are fully persuaded that now is the proper time for its commencement. Delays are the refuge of weak minds, and to procrastinate on this occasion is to show a culpable inattention to the bounties of Nature; a total insensibility to the blessings of Providence, and an inexcusable neglect of the interests of society. If it were intended to advance the views of individuals, or to foment the divisions of party; if it promoted the interests of a few, at the expense of the prosperity of the many; if its benefits were limited as to place, or fugitive as to duration, then indeed it might be received with cold indifference, or treated with stern neglect; but the overflowing blessing, from this great fountain of public good and national abundance, will be as extensive as our country, and as durable as time.

The considerations which now demand an immediate and an undivided attention to this great object are so obvious, so various, and so weighty, that we shall only attempt to glance at some of the most prominent.

In the first place, it must be evident that no period could be adopted in which the work can be prosecuted with less expense. Every day augments the value of the land through which the canal will pass; and when we consider the surplus hands which have been recently dismissed from the army into the walks of private industry, and the facility with which an addition can be procured to the mass of our active labour, in consequence of the convulsions of Europe, it must be obvious that this is now the time to make those indispensable acquisitions.

2. The longer this work is delayed, the greater will be the difficulty in surmounting the interests that will rise up in opposition to it. Expedients on a contracted scale have already been adopted for the facilitation of intercourse. Turnpikes, locks, and short canals, have been resorted to, and in consequence of those establishments, villages have been laid out, and towns have been contemplated. To prevent injurious speculation, to avert violent opposition, and to exhibit dignified impartiality and paternal affection to your fellow citizens, it is proper that they should be notified at once of your intentions.

3. The experience of the late war has impressed every thinking man in the community with the importance of this communication. The expenses of transportation frequently exceeded the original value of the article, and at all times operated with injurious pressure upon the finances of the nation. The money thus lost for the want of this communication, would have perhaps defrayed more than one half of its expense.

4. Events which are daily occurring on our frontiers, demonstrate the necessity of this work. Is it of importance that our honourable merchants should not be robbed of their legitimate profits; that the public revenues should not be seriously impaired by dishonest smuggling; and that the commerce of our cities should not be supplanted by the mercantile establishments of foreign countries? then it is essential that this sovereign remedy for maladies so destructive and ruinous should be applied. It is with inconceivable regret we record the well known fact, that merchandise from Montreal has been sold to an alarming extent on our borders for 15 per cent. below the New-York prices.

5. A measure of this kind will have a benign tendency in raising the value of the national domains, in expediting the sale, and enabling the payment. Our national debt may thus, in a short time, be extinguished. Our taxes of course will be diminished, and a considerable portion of revenue may then be expended in great public improvements; in encouraging the arts and sciences; in patronizing the operations of industry; in fostering the inventions of genius, and in diffusing the blessings of knowledge.

6. However serious the fears which have been entertained of a dismemberment of the Union by collisions between the north and the south, it is to be apprehended that the most imminent danger lies in another direction, and that a line of separation may be eventually drawn between the Atlantic and the western states, unless they are cemented by a common, an ever acting, and a powful interest. The commerce of the ocean, and the trade of the lakes, passing through one channel, supplying the wants, increasing the wealth, and reciprocating the benefits of each great section of the empire, will form an imperishable cement of connexion, and an indissoluble bond of union. New-York is both Atlantic and western, and the only state in which this union of interest can be formed and perpetuated, and in which this great centripetal power can be energetically applied. Standing on this exalted eminence, with power to prevent a train of the most extensive and afflicting calamities that ever visited the world, (for such a train will inevitably follow a

dissolution of the Union,) she will justly be considered an enemy to the human race, if she does not exert for this purpose the high faculties which the Almighty has put into her hands.

Lastly. It may be confidently asserted, that this canal, as to the extent of its route, as to the countries which it connects, and as to the consequences which it will produce, is without a parallel in the history of mankind. The union of the Baltic and the Euxine; of the Red Sea and the Mediterranean; of the Euxine and the Caspian; and of the Mediterranean and the Atlantic, has been projected or executed by the chiefs of powerful monarchies, and the splendour of the design has always attracted the admiration of the world. It remains for a free state to create a new era in history, and to erect a work more stupendous, more magnificent, and more beneficial, than has hitherto been achieved by the human race. Character is as important to nations as to individuals, and the glory of a republic, founded on the promotion of the general good, is the common property of all its citizens.

We have thus discharged with frankness and plainness, and with every sentiment of respect, a great duty to ourselves, to our fellow citizens, and to posterity, in presenting this subject to the fathers of the commonwealth. And may that Almighty Being, in whose hands are the destinies of states and nations, enlighten your councils and invigorate your exertions in favour of the best interests of our beloved country.

To the Honourable the Senate and Assembly of the State of New-York.

During the late war, it was impracticable to carry on any further operations to forward the objects of their appointment, by pursuing the surveys and levels heretofore commenced, with a view to ascertain the most desirable route for the proposed canal from lake Erie to the tide-waters of the Hudson river.

Referring therefore to their former reports, respecting the practicability of effecting this important object, they will briefly add, that their opinions have been confirmed by reflection and additional inquiries on the subject. And particularly so far as respects the cost, they are satisfied that it will not exceed the calculation they have already submitted. It now remains for the legislature to provide means to enable the commissioners to engage a competent professional engineer to examine minutely the whole of the ground, and decide on the most expedient route. Experience in similar operations in Europe, has shown that an error in regard to this may cause the useless expenditure of vast sums of money. The surveys and levels which the commissioners have caused to be taken will have anticipated what an engineer would direct as an indispensable, preparatory work, and will put information into his hands which will enable him at once to take such a view of the field of operation, as to save much time and expense.

These preparatory operations, your commissioners therefore consider as essential to economy, since they will, with but little time employed in traversing the ground, by the person to whom the work will be intrusted, enable him to fix on the precise route, on which the best judgment, with the best information, would finally determine, with less danger of error than if he were left to enter on his business, an entire stranger to the facilities or difficulties which the country presents. To select a suitable person to perform this most important part of the work, will require the utmost caution and deliberation. The same causes which suspended the duties of the commissioners, have been the principal obstacles to the selection and employment of a capable engineer. There are few persons of this description in Europe, and there is every inducement for preferring our own countrymen, if the requisite scientific and practical knowledge can be formed.

From the number and the respectability of the applications now before the legislature, in favour of an immediate commencement and vigorous prosecution of this great national work, it is evident that the immense advantages which would result from its completion, are duly appreciated by our fellow citizens; and it only remains for the legislature to sanction, by their approval, an undertaking which combines in one object the honour, interest, and political eminence of the state.

In a time of peace like the present, the commissioners have the most undoubted assurance, that a loan on the credit of the state can be obtained for a million of dollars, with which to commence the work, and for as much more thereafter as may be required, at a rate of interest at or under six per cent. Perhaps, however, better means may be devised; and they beg leave to remind the legislature, that the lands already offered to them by private individuals, near whose property the canal will pass, are very valuable, and that further similar donations may be seasonably expected. If it should be judged expedient to make that part of the canal first, which is best calculated to yield an immediate and most profitable return for the expense, the Commissioners are of opinion that the route from Rome to the Seneca river will be the most eligible; and would moreover have the most immediate tendency to divert the trade from passing down the Oswego river to lake Ontario and Montreal: to permit which would be improvidently to abandon to a foreign and rival nation, commercial advantages which ages may not enable us to reclaim. The difficulty of diverting the fixed currents of trade is obvious and well known; and the importance of the policy of directing that of the western section of the state to the Hudson, is equally evident: and the commissioners conceive that the present moment, while this section of the state is yet comparatively in its infancy, is most favourable for forming and establishing such connexions between the lakes and our Atlantic waters, as will effectually disappoint the views of our rivals, and promote the honour and advantage of the state.

While the commissioners cannot express in terms sufficiently emphatic, their ideas of the incalculable benefits which will arise from a canal navigation between the great western lakes and the tide waters of the Hudson, they fully appreciate the advantages of connecting the waters of Champlain and the Hudson. And they most respectfully represent to the legislature the expediency of adopting such preliminary measures as may be necessary for the accomplishment of this important object.

The commissioners who signed and presented this memorial were, S. V. Rensselaer, De Witt Clinton, Simeon De Witt, W. North, Thomas Eddy, Peter B. Porter, and Charles D. Cooper.

The law authorizing the actual survey of the ground over which the contemplated canals were to pass, was enacted April 17th, 1816. Commissioners were appointed under this law, who met and organized a board on the 17th day of May, 1816, and proceeded to the fulfilment of their duties. This board made their report to the legislature on the 15th of February, 1817. From this report it appears, the board was required to perform the following specific duties:

1st. To devise and adopt such measures as shall be requisite to facilitate and effect a communication, by canals and locks, between lake Erie and the navigable waters of Hudson's river, and also between lake Champlain a[illegible] navigable waters.

[illegible] ex[illegible] the country [illegible] determining the most eligible routes, [illegible] contemplated canals, to cause surveys and [illegible] taken, and maps, field-books, and draughts to be made, and to adopt and recommend proper plans for the construction and formation of the said canals, and of the locks, dams, embankments, tunnels, and aqueducts; and to cause all necessary plans, models and draughts thereof to be executed.

3d. To calculate and estimate the expense of the above operations.

4th. To ascertain whether to any, and to what amount, and upon what terms, loans of money can be procured, on the credit of the state, for the above purposes—and,

5th. To apply for donations of land or money, in aid of those undertakings, to the United States, to states interested, to corporate bodies, and to individuals.

The report contains an actual survey and level of the canal route, from the mouth of Buffalo creek into lake Erie, at the town of Buffalo, to the mouth of Schoharie creek. The Hudson and Erie canal was divided into three sections; the eastern, middle, and western. The eastern was made to extend from Rome to the Hudson river; the middle from Rome to the Seneca river; and the western from Seneca river to Buffalo. To superintend the surveys and levels on these respective sections, engineers were appointed to each. Charles C. Broadhead, Esq. had the superintendance of the eastern; Benjamin Wright, Esq. of the middle; and James Geddes, Esq. of the western.

The extent and accuracy of the work done in the summer and autumn of 1816, in surveying and leveling 278 miles, are really matters of admiration, and exhibits a diligence and ability rarely met with, perhaps never excelled in similar enterprises. It would be incompatible, in a general view, to give the minute detail of the operations of the engineers: all that can be necessary to a competent knowledge of the country will be comprised in our geographical sketch. To those who may require more minute information on the subject, we would recommend Col. Haines's work on the commencement and progress of the New-York canals.

As means of comparison with the actual result we here insert the aggregate of distances and expense, premising that the northern route between Genesee river and Tonnewanta creek has been definitively decided upon for that part of the canal.

Recapitulation of expenses.

From lake Erie to a point 11 miles up the Tonnewanta, . .	$205,877
Tonnewanta to the Seneca river, .	1,550,985
Seneca river to Rome, . . .	853,186
Rome to the Schoharie creek, . .	1,090,603
Schoharie creek to Albany, . . .	1,106,087
Add for general expenses, . .	75,000
In the aggregate, . . .	$4,881,738
But, if the route south of the mountain ridge, the country west of the Genesee river, is adopted, in preference to the northern route, then deducting	$309,925
The aggregate of expense will be .	4,571,813

Of distances.

	Miles.	Chains
From lake Erie to the point up the Tonnewanta,	27	0
Tonnewanta to Seneca river, . .	136	2½
Seneca river to Rome, . . .	77	
Rome to Schoharie creek, . . .	71	27
[illegible] Albany, . . .	42	
[illegible] . .	353	29½

[illegible] d fall.

From lake Erie to Seneca river, a fall of	194 ft. by	25 locks.
Seneca river to Rome, a rise of	48 50	6
Rome to Schoharie creek, a fall of	132.85	16
Schoharie creek to Albany, a fall of	286	30
The aggregate of rise and fall, in feet, is	661.35 by	77 locks.

Lake Erie is 564.85 feet higher than the Hudson, and 145½ feet higher than Rome.

The average expense, per mile, of this canal, according to the foregoing estimates, taking the north route beyond the Genesee river, is a little more than $13,800.

The commissioners closed this report by expressing their financial views, and expressing their opinion that the necessary funds could be procured in the United States on loan.

The commissioners who signed this report were, De Witt Clinton, S. V. Renssalaer, Samuel Young, and Myron Holley.

The same board subjoined a few observations respecting the northern canal, from the Hudson to lake Champlain. As those reflections and statements were brief, and led to the adoption of measures to carry into effect that canal also, they are here given entire.

On the Northern canal the commissioners observe, that "the advantages which will result from the connection of lake Eric with the navigable waters of the Hudson, by means of a canal, have been so frequently elucidated, and are indeed so obvious to every one who possesses a correct geographical knowledge of the west, that it has been deemed unnecessary to enumerate them. But, presuming that the benefits to be derived from a similar communicatian with lake Champlain are not fully understood or duly appreciated, the commissioners ask the indulgence of briefly pointing out a few of the most prominent of these benefits.

That part of this state which is contiguous to lakes George and Champlain abounds in wood, timber, masts, spars, and lumber of all kinds, which, transported by the Northern canal, would find a profitable sale along the Hudson and in the city of New-York, instead of being driven, as much of those articles have heretofore been, to a precarious market, by a long and hazardous navigation to Quebec.

Some idea may be formed of the immense quantity of lumber which would he conveyed on the contemplated canal, from the following statement, made on the best authority, and which embraces only that small section of the northern part of this state, from whence the transportation is carried on to the city of New-York, or to intermediate markets.

Within that tract of country, embracing the borders of lake George, and the timber land north and west of the great falls in Luzerne, there are annually made, and transported to the south, two millions of boards and plank, one million feet of square timber, consisting of oak, white and yellow pine, besides dock logs, scantling, and other timber to a great amount.

A considerable portion of the northern part of this state is rough and mountainous, and, in a great measure, unfit for agricultural improvements. These broken tracts are covered with native forests, which, by the contemplated canal, would furnish vast supplies of wood and lumber for many years; and thus the great and increasing population which occupies the margin of the Hudson would be supplied with boards, plank, timber, fencing materials, and even fuel, with less expense than from any other quarter; while, at the same time, the lands to the north, considerable tracts of which belong to the people of this state, would he greatly increased in value.

The mountains in the vicinity of lakes George and Champlain produce a variety of minerals, among which are found, in inexhaustible quantities, the richest of iron ores. Several forges are in operation in the counties of Washington, Warren, Essex, and Clinton, the number of which may be indefinitely increased: and the iron which they produce is very little, if at all, inferior in quality to the best iron manufactured in the United States: nor can it be doubted that, after the completion of the contemplated canals, the middle and western part of this state would be furnished with this necessary article on more advantageous terms than it can at present be procured.

The inhabitants of a large tract of country on both sides of lake Champlain, embracing a considerable portion of the state of Vermont, would find, by the northern canal, a permanent market in the city of New-York, or at intermediate places, for their pot and pearl ashes, and also for all their surplus agricultural productions, from whence they would also be cheaply supplied with all the necessary articles of foreign growth.

The iron of the northern part of this state, which at present is unwrought in the mine, and the fine marble of Vermont, which now lies useless in the quarry, would be converted to useful and ornamental purposes in the west, in exchange for salt and gypsum; and thus the large sums which are annually sent abroad for the purchase of iron, of salt, and of gypsum, would be retained among our citizens, and added to the permanent wealth of the state.

In short, the connexion of lake Champlain with the Hudson, by means of a canal, would greatly enhance the value of the northern lands; it would save vast sums in the price of transportation; it would open new and increasing sources of wealth; it would divert from the province of Lower Canada, and turn to the south, the profits of the trade of lake Champlain; and, by imparting activity and enterprise to agricultural, commercial, and mechanical pursuits, it would add to our industry and resources, and thereby augment the substantial wealth and prosperity of the state.

The examination and levels for this canal have been made under the direction of the commissioners, by Col. Lewis Garin, and the line for the same has been marked out upon the maps herewith presented. There are two places of departure from the Hudson, in order to connect that river with lake Champlain, each of which affords a very favourable route, in point of soil to be excavated, and of matercals for the artificial works. One of these routes, by commencing at the mouth of fort Edward creek, and pursuing the valley of that creek to the summit level, and then following the ravine of Wood-creek, will reach Whitehall in the distance of twenty-two miles. This route was formerly deemed most eligible by a board of commissioners composed of general Schuyler and others. It is, however, supposed, by the engineer, that the other route may be preferable, which commences about six miles further down the river, near the mouth of Moses' kill, and which by the natural channel of this kill, and of Dead-creek, joined to a short length of artificial canal, forms the summit level from whence it proceeds—partly by the natural channel of Wood-creek, and partly by artificial cuts, which greatly shorten the distance to Whitehall. The length of this route is twenty-eight miles, and it passes over a soil which is, in geneaal, remarkably favourable, consisting principally of vegetable mould, loam and clay. At the northern termination of the canal, a few yards of limestone excavation will be necessary; this, however, is not deemed an unfavourable circumstance, as the stone are of such a quality as will be useful in the construction of locks, and it may be remarked, that the materials for the construction of the locks between lake Champlain and the Hudson can be procured with little difficulty.

Between the Hudson and lake Champlain nine locks will be necessary, viz. three at the Hudson of 7,779 feet lift each, by which the summit-level will be attained, and by a deep cutting, the greatest depth of which will be 12,465 feet, and the length of which is about two miles, the summit-level will be extended fifteen miles, and will terminate about one mile south of fort Ann. At this place two locks will be necessary of 6,217 feet lift each. Between this point and Whitehall, two locks, the first of 8,223 feet lift, and the next of 9,243 feet lift, are to be made. At Whitehall, the canal is to be connected with lake Champlain by two locks of 8,550 feet lift each.—About fifteen miles of this route will need no excavation, as the canal for that distance will occupy the natural channels of Moses' kill, Dead creek and Wood creek. In order to turn off as much as possible the superfluous waters of freshets, and to ensure at all times a sufficiency of water on the summit-level, it is proposed to erect a dam across Half-way brook of eighteen feet in height, half a mile above the mouth of the said brook, and by a natural ravine leading to the south, to direct so much of the water of said brook to the summit-level, and from thence by several water-weirs, into the Hudson, as may be necessary for the convenience of the canal.

The water in the canal is not to be less than thirty feet wide at the surface, twenty feet at the bottom, and three feet deep, and the locks to be seventy-five feet long and ten feet wide in the clear.

By the mode of calculation heretofore adopted by the commissioners, the whole expense between lake Champlain and the Hudson, at the mouth of Moses' kill, will not exceed two hundred and fifty thousand dollars.

From the mouth of Moses' kill it is proposed to improve the channel of the Hudson for the purposes of navigation as far south as the village of Stillwater, at the head of Stillwater falls. This may be effected in the following manner. By erecting a dam of three feet in height across the Hudson, at the head of fort Miller falls, the river above as far as fort Edward, would at all times afford a sufficiency of water for boats drawing three feet.

To overcome the descent of fort Miller falls, a side cut or artificial canal of about one mile in length, and with two locks of 10,321 feet lift each, will be necessary. These works, including the dam, locks, excavation, towing path, and all other expenses, may be estimated at fifty thousand dollars.

Two and a half miles below the south end of this canal, at the head of Saratoga falls, a dam three feet in height is to be made across the river, and a side cut round the falls similar to the above, of about one mile in length, with two locks of 6,198 feet lift each. It is believed that all the artificial works at this place may be constructed for thirty-five thousand dollars.

Thirteen miles below this place, at the head of Stillwater falls, another dam of three feet in height, will in like manner ensure a good boat navigation up to the Saratoga falls.

The cost of this dam, the construction of a towing-path, with several bridges, the purchase of Schuyler's mill, which it is supposed will be necessary, together with all the other expenses of this section, are estimated at fifty thousand dollars.

From the village of Stillwater, at a point above the dam last mentioned, it is proposed to cut an artificial canal to the village of Waterford, where it is to be connected with the Hudson. This canal will be supplied with water from the river at its upper end. Its length will be nearly twelve miles, and the whole descent is 76,464 feet: which will require eight locks. The excavation of this canal for some distance near the upper end, will be considerably expensive, as it passes through a slate rock; the middle and lower parts, however, are very favourable.

The expenses from Stillwater to Waterford may be estimated as follows:

76 feet lockage at $1000 per foot, . .	76,000
12 miles of excavation and towing path, with bridges, culverts, and other necessary works, at an average of $30,000 per mile,	360,000

Recapitulation of Expenses.

From Whitehall to the Hudson, . -	$250,000
Dam, side cut, and other works at fort Miller falls, ...	50,000
Do. at Saratoga falls, ...	35,000
To Stillwater, including dam, &c. . .	50,000
From Stillwater to Waterford, including lockage,	436,000
Add for contingencies, engineers, and superintendance, ...	50,000
Total,	$871.000

Whether the canal from lake Champlain enters the Hudson from fort Edward creek at Moses' kill is not very material in the estimate of expense; and the commissioners wish to be explicitly understood, that they consider this question as still open, and as one which will require mature deliberation. It is ascertained that both routes are equally practicable.

The termination of the northern canal in the Hudson, at Waterford, will afford the cities of Albany and Troy, and the villages of Lansingburgh and Waterford, a full participation of its benefits; and its approximation to the great western canal will open the most beneficial channels of communication between every great section of the country, and furnish every facility for promoting the activity and enlarging the sphere of inland trade, which constitutes one of the principal elements of national opulence, prosperity and greatness. And before the lapse of half a century, those who succed us will witness, in the consolidation of those cities and villages into one great city, a union of interests and sympathies, which will totally dissipate the apprehensions and jealousies that may now exist.

The favourable impression made upon the legislature of New-York by these reports, produced the acts of April 15th and 17th, 1817, by which the following gentlemen were appointed commissioners, Stephen Van Rensselaer, De Witt Clinton, Samuel Young, Joseph Ellicott, and Myron Holley * These acts provided for the commencement of the two great canals of New-York, henceforth known by the titles of Western and Northern.

On January 31st, 1818, the board, under the act of April 17th, 1817, made their report, by which it appeared, that the board met as early in 1817 as the season would admit, and, after careful examination, made at the outset two very important changes in the previous arrangements. One was expressed in the following terms: "This re-examination induced a belief, that the short summit level at Rome, mentioned in the report, and indicated on the map of last year, might be entirely avoided, and instead thereof, a long summit obtained, extending from the Mohawk river to the vicinity of the salt works at Salina. By this arrangement the cost of constructing two locks, the delay of passing them, and the future expense of repairs, would for ever be saved and prevented. Add to this, the new and extended summit would command, at all times, an inexhaustible supply of water, embracing the Oriskany creek, the Mohawk river, Wood creek, and the more numerous and copious streams west of Wood creek, which cross the line of the canal, and discharge themselves into Oneida lake. After a minute and laborious examination, this alteration was adopted."

The next change was an extension of the middle section from Rome to Utica. The reasons assigned by the commissioners for this extension were, that "The law of April 5th, 1817, directs the construction of the middle section, 'between the Mohawk and Seneca rivers,' without designating any point of union with either of the said rivers; the commissioners, therefore, believed themselves vested with a discretionary power, which would authorize them to approach either of the said rivers, at such place as would most conduce to the public good. Not only from actual observation, but from information derived from the most unquestionable authority, it was ascertained that the Mohawk river, from Rome to Utica, is extremely serpentine in its course; and that its navigation, in low water, is much more difficult and imperfect than below the village of Utica; so much so, that this part of the route of the western inland lock navigation frequently becomes a portage; boats being lightened or unloaded west of Rome, and their cargoes carried by land to Utica, where they are reloaded into boats and transported down the Mohawk. Anticipating that the channel of the Mohawk river may be used for the purposes of navigation, for some time after the completion of the middle section, and before the eastern section will be constructed, it was deemed advisable to extend the middle section as far east as the village of Utica."†

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* Haines, page 264.

† Haines, page 275.

These preliminary steps, and some other necessary arrangements being made, the first contract was dated the 27th June, 1817, and, on the 4th of July following, this stupendous work was commenced, in presence of the commissioners.

To follow the future advance of executing the great western canal cannot be sufficiently interesting to the public to justify swelling this article, already expanded to considerable length. Our view of the subject will, therefore, be closed by a brief geographical survey of the canal route, and of those parts already completed. It may be necessary, however, to premise, that our view of the finished parts has been abridged from the report of the canal commissioners of the state of New York, made April 15th, 1821, as the report of 1822 has not been received.

The deficiency in the statement of the present condition of the canals cannot, nevertheless, be great, as those parts placed under contract early in 1821 are generally finished.

Turning our view towards the basin of the Hudson, we find the Mohawk branch entering that stream 9 miles above the city of Albany, after having flowed down a deep valley from Rome of within a small fraction of 105 miles. The Mohawk valley is peculiar in the regular acclivity of the opening slopes of the hills in general. It is precipitous but in a few places. The river is rapid, very sinuous in its course, and filled with innumerable small islands. One chain of mountains crosses the Mohawk valley, and forms the little falls, about 70 miles above its mouth. Another ledge of rocks, 2 miles above the mouth, produces the Cohoes falls. These are the only absolute cataracts in this river between Rome and Waterford.

The entire Mohawk valley below Rome has a rise and fall from and to tide water of 420 feet. In this distance nearly three-tenths, or 120 feet of the entire acclivity, lies between Albany and the head of Cohoes fall, which is contemplated to be rendered navigable by 12 locks. From the Cohoes to Schenectady, the bed of the river rises about 74 feet, in which 8 locks are intended to be placed. From Schenectady to the mouth of Schoharie river, the Mohawk valley again rises 92 feet, giving an entire fall from Schoharie to Albany, of 286 feet. In the space between Schenectady and Schoharie, 10 locks are designed to be erected. With this rise of 286 feet, and 30 locks, the canal is to extend 50 miles, with very nearly an average of 6 feet inclination to the mile.

Above Schoharie creek, the valley rises less rapidly than below, and in a distance of 36½ miles has an acclivity of about 80 feet, to overcome which 9 locks are to be constructed. From the Little Falls, to the mouth of Myer's creek, 12 miles, is a rise of 54 feet. This attains the great summit level of the Mohawk valley, reaching to between Manlins and Salina, 69½ miles. This summit is within a small fraction of 420 feet above the tides of the Hudson.

From Myer's creek to Utica is 8 miles, and at the latter place closes the eastern section of the western canal, in all its length 109 miles, of which the greatest part above the Little Falls is already finished and in use. Engineers, Charles Broadhead, and Canvas White, Esqrs. The entire canal route down the Mohawk river follows the right or south shore of that stream. Nine locks are intended between Myer's creek and the Rome summit level.

Taking 9½ miles, the distance from Myer's creek to Utica, from 69½ miles, leaves 60 miles. The latter distance the summit level extends west of Utica. At the termination of the summit level, a depression of 26 feet by 3 locks, in a distance of 1½ miles, reaches the outlet of the Salina side canal.

Thus far, from the mouth of Myer's creek, a distance of 71 miles, the ample supply of water for the canal is obvious, from inspection on a good map of the country. Independent of a great number of smaller creeks and brooks, this section of the canal is fed by the various branches of Cheteningo, Oneida, and Wood creeks, and the Mohawk river.

West from the Salina canal, the Grand canal follows the latter mentioned level near 2 miles, at the end of which, by a lock of 6 feet lift, it is led to another level 7 miles in length, extending to Nine-mile creek, where another lock of 11 feet lift attains the highest summit between Salina and Seneca river. The latter level extends to Jordan on the Skaneatelas outlet, 12 miles. Here again the canal falls 11 feet by a lock, and following the level thus obtained 9 miles, to Owasco outlet, at Bucksville. From the latter place the canal descends by 3 locks of 9, 9, and 7 feet, in a distance of 6 miles to the end of the middle section, near Montezuma on Seneca river.

From the Skeneateles lock to Seneca river, the Grand canal, besides from two other considerable creeks, receives an inexhaustible supply of water from the outlets of the Owasco and Skeneateles lakes. The entire length of the middle section is 96 miles. Engineer, James Wright, Esq.

From the Seneca river to lake Erie, the canal is to be supplied by that lake, and innumerable other sources of water from the interior of the state of New-York. The entire rise and fall between the extremes of this section is 194 feet, to be overcome by 25 locks, averaging near 8 feet lift. The canal crosses the Seneca river immediately below the mouth of the outlet of Cayuga and Seneca lakes, and thence follows the left shore of that river, to a short distance above the outlet of the Canandaigua lake, and the village of Lyons. Seneca river is indeed formed at Lyons, by the junction of the outlet of Canandaigua and Mud creek.

After passing the Seneca river, the canal, by two locks, of 5 and 6 feet lift, in a distance of 12 miles, reaches Clyde. From the latter place to Lyons, 9 miles, the canal again rises 13 feet, by 2 more locks, of 6, and 7 feet. Above the last lock, the canal crosses Mud creek, by a lock of 10 feet lift, and thence 6 miles, follows one level; at the end of which it again rises 24 feet, by 3 locks, of 8 feet each. Extending thence 8 miles upon one level, by which it passes the village of Palmyra, and again crosses Mud creek. At the crossing of Mud creek, two locks, of about 8 feet each, place the canal upon the Irondequot level, upon which it is carried, down the valley of that stream, 21 miles, to within 4 from the right bank of Genesee river at Rochester. The canal has, therefore, gained an ascent of 72 feet, by 10 locks, in a distance of 60 miles, from the extreme depression on the Seneca river, to the western extremity of the Irondequot valley.*

The actual labour, of any consequence, hitherto made upon the Grand canal, has all been performed eastward from the Genesee river, to Minden, opposite Palatine, on the Mohawk, a distance of 191 miles. This extent is completed, or nearly so, and comprises 60 miles of the western, all the middle, and 35 miles of the eastern section; or considerably above one-half the entire canal from Albany to Buffalo.

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* See Mr. Geddes's letter.

At the western termination of the Irondequot valley, a very abrupt rise of about 40 feet will place the canal upon a level which extends about 60 miles to Eighteen Mile creek. At the latter point, another abrupt rise of 81 feet by 8 locks, attains the summit level of lake Erie; following that level 27 miles, reaches the mouth of Buffalo creek, at the town of Buffalo.

The following extracts from the report of the canal commissioners for 1821, will close our remarks on the Grand canal, and, we trust, with what is already given, will serve, amply, to place before our readers a view of that very important work.

The commissioners commence by adducing their reasons for finally adopting the northern route for the canal, between Genesee river, and Tonnewanta creek; and thus proceed:

"Impressed with these considerations, we have concluded that prudence would not permit us to adopt any route west of the Genesee river, which should rise above the level of lake Erie. The most northerly route indicated, on the engraved map of 1817, does not rise above that level. To that route, therefore, during the last year, our attention has been specially directed. And we have constantly employed David Thomas as engineer, with all the necessary assistants, upon it, from May to late in November. The results of the examination made by this party have been much to our gratification, for they have confirmed our former most favourable impressions, after having been produced with great care, diligence, and skill.

The survey of Mr. Thomas has been extended, from Genesee river to the Tonnewanta creek, a distance of a little more than seventy-two miles, including the deep cutting through the mountain ridge. And throughout this survey, the face of the country,—the nature of the earth to be excavated, and the character of the streams to be passed, are so well understood, that the canal-line may be speedily prepared for the contractor.

From the Genesee river easterly, there are fifty-one miles and a quarter of the canal line either completed, or under contract, including the whole distance from that river to Montezuma, except about nine miles. These nine miles have not heretofore been placed in a condition to be opened, because the appropriations would not warrant entering into engagements with contractors for the whole distance between Rochester and Montezuma, and because there is now, contiguous to these nine miles, nearest the latter place, and extending from near one end of them to the other, a circuitous and imperfect navigation, by means of the Canandaigua outlet, and the Seneca river. With the ample appropriations made at the present session of the legislature, it will be the duty of the canal commissioners to complete the canal through these nine miles, with all possible despatch.

In the fifty-one miles and a quarter of the canal line above mentioned, there have been two important deviations from the route which was traced in 1816, both of which are deemed improvements. One of them is in the place of crossing the valley of the Irondequot creek Here it was found, that, instead of establishing the line, so as to require an embankment twenty chains long, on the top, and sixty-five feet in height, from the bottom of the valley, it might be so located, by carrying it a little farther north, as to divide this great embankment into two parts, both of which would not contain more cubic yards than the one required on the first route. And, as the earth in this vicinity consists too exclusively of sand and gravel, to be well adapted to embankments, this division was thought judicious, and the new line was adopted. But since its adoption, instead of the largest of the two embankments, we have concluded to substitute an aqueduct of wood. It was found, by calculation, that the construction of this embankment would involve the expenditure of a capital so large, that the interest of it would exceed the sum required to complete the aqueduct, together with the interest thereon, computing the interest, in both cases, for the probable duration of the aqueduct. Economy, therefore, induced us to make the substitute. We had, however, a strong additional inducement to the course which we adopted; and this was, the safety of the work after its completion. It has already been mentioned, that the quality of the earth near the embankment is not fit for use in it. When, by means of the aqueduct, the canal is rendered navigable, good earth for the embankment may be economically brought from a distance, in boats; and the embankment may be constructed of such materials as will be safe, and, at the same time, raised and completed in such a way, as to cause no interruption in the use of the canal by the removal of the aqueduct.*

The other alteration consists in carrying the canal line south of Mud creek, from a point a little west of Palmyra village, to a point a little west of the village of Lyons, the distance between these two points being about fourteen miles. The line, as explored in 1816, was all the way on the north side of this creek. But the new route is recommended, by its shortening the length of the canal two miles and fifty-two chains, by its being less expensive, and by its passing through earth more suitable for insuring the canal against injurious accidents, when it shall be filled with water. This new route was examined, and found eligible, by Nathan S. Roberts, Esquire, one of our resident engineers, whose vigilance and industry deserve much praise; though, in justice to the sagacity of Judge Geddes, the engineer who explored the western section of the Erie canal, with so much perseverance and good judgment, in 1816, it ought not to be forgotten, that he suggested the propriety of surveying this new route.

The contracts west of the Middle section, besides grubbing and clearing, excavation, embankment, and fencing, provide for the construction of the following works, to wit:

Fifteen locks, of various lifts, but which, in the aggregate, furnish the means of ascending or descending one hundred and eighteen feet. One of these locks is nearly completed, in the handsomest and most substantial manner; and the materials for all the others are now chiefly procured and delivered:—

Twenty stone culverts, of different sizes, all to be arched, and placed upon permanent foundations, and more than half of which are now finished, with great solidity and beauty:—

Five aqueducts, of which one is to cross Mud creek, near Lyons, and to be constructed entirely of stone, with three arches of thirty feet span each, one is to cross the same creek near Palmyra, and to be constructed of stone abutments and piers, with a wooden trunk resting upon them; two are to cross the valley of Irondequot creek, and a narrow ridge adjacent thereto, these two being to be built exclusively of wood, and to extend, in the aggregate, a length of 1350 feet; and one is to cross Black brook, in the town of Galen, and to consist of stone abutments supporting a wooden trunk. The foundations of these aqueducts are in considerable forwardness, and most of the materials, for their completion, are delivered:—

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* See Mr. Geddes's letter, p. 346.

Forty road-bridges and a smaller number of Occupation-bridges. About half of these bridges are erected, and all of them which have been contracted for, during the last season, are required to be six inches higher above the top water line, and to be made eight feet wider, between their abutments, than those were, which had been previously built on the middle section.

All the above contracts have been prosecuted with great zeal and success, insomuch that, in the aggregate, the fifty-one miles and a quarter are more than half done; and nine miles have been in such condition, as to allow of an experimental admission of water. A large part of this extent runs through the sands of Perrinton and Pittsford, where we have always had a great apprehension of difficulty, by leaks and breaches. Through these sands we had taken the precaution to have the banks made much thicker than usual, and with a greater slope; and the effects of admitting the water, to the depth of about two feet, have been satisfactory and encouraging.

Having adopted that route for the canal, which at every departure from the level of lake Erie, in its progress eastward, will descend, till it reaches the Seneca river, we entertain no doubt of an abundant and permanent supply of water, for every part of the canal line. But, in order to provide against any possibility of danger on this subject, it is intended to construct the canal through the dry region, between the locks, at the Mountain ridge and the Genesee river, with a descent towards the east, of one or two inches in every mile; the necessary effect of which will be, to save the expense of at least one lock, and to induce a current of so much water from lake Erie, towards the east, as will leave but little to be required from the Genesee river: and this little may be still reduced, if it shall ever become expedient, by a feeder from the Irondequot creek, a copious and equable stream, which it was formerly supposed could not be drawn upon for the canal, but which, by the enterprising zeal of David S. Bates, Esquire, one of our resident engineers, has been found capable of being taken into it, at Pittsford, near the west end of a level, about thirteen miles in length. From this level eastward, there might be obtained a sufficient supply of water, from the Canadaigua lake, Mud creek, and several other sources, for all the demands of the canal, if the Genesee river were annihilated.

On the middle section of the canal we have placed mile-boards, duly painted and numbered, from one end to the other. And the whole length of it, as measured from Genesee-street, in the village of Utica, to the lock which connects it with Seneca river, without including the Salina side cut, is found to be a few chains more than ninety-six miles.

The navigation of this section commenced throughout in May last. But, as there were several places on it requiring repairs, and as it was soon discovered that our supply of water would not be adequate to the requirement of an extensive and increasing transportation, some time was occupied in repairing breaches, in strengthening weak places, especially those where the high embankments had settled, and in opening several new feeders. And we did not think we should be justified in asking toll till the first of July. From that time, till the ice prevented all passing, there has been received for toll, on this section, the sum of $5244 34.

This amount has been collected, by charging at the following rates, which were agreed upon at a meeting of the Canal Commissioners, and duly advertised, to wit:

On Salt, 5 mills per ton, per mile, (7 bbls. of 5 bushels each, or 40 bushels in bulk, being a ton.)
Gypsum, 5 mills per ton, per mile.
Flour, meal, and all kinds of grain, salted provision, pot and pearl ashes, one cent per ton, per mile.
Merchandise, two cents per ton, per mile.
Timber, squared and round, 5 mills per hundred solid feet, per mile.
Boards, plank and scantling reduced to inch measure, and all siding lath, and other sawed stuff, less than one inch thick, 5 mills per thousand feet, per mile.
Shingles, one mill per thousand, per mile.
Brick, sand, lime, iron-ore, and stone, 5 mills per ton, per mile.
Rails and posts for fencing, two cents per thousand, per mile.
Wood for fuel, one cent per cord, per mile.
All fuel to be used in the manufacture of salt, to pass free.
Boats made and used chiefly for the transportation of property, on each ton of their capacity, one mill per mile.
On boats made and used chiefly for the carriage of persons, 5 cents per mile of their passage.
Staves and heading, for pipes, one cent per thousand, per mile.
Staves and heading, for hogsheads, 7 mills per thouthousand, per mile.
Staves and heading, for barrels, or less, 5 mills per thousand, per mile.
All articles not enumerated, one cent. per ton, per mile.

Besides the above mentioned amount of toll received, there has been collected, at the Little falls of the Mohawk, since the rights of the Western Inland Lock Navigation Company have been transferred to the state, the sum of $450 56 for toll, the toll having been charged, from Rome to the lower lock at the Little falls, at the same rates per mile as are stated in the above table, in reference to the canal line.

The system adopted by us, for regulating the collection of tolls, requires, that whenever any property, chargeable with toll, arrives at one of the places of collection, the person intrusted therewith should exhibit a bill of particulars, containing an exact account of all the property, arranged under different heads, according to the different rates of toll which it may be liable to pay; and containing also, the name of the boat and its tonnage, if the articles are conveyed in a boat, together with the place from which it comes, and that to which it is destined. When such a bill is presented, it is made the duty of the collector to examine the property, and ascertain whether it corresponds with the bill. If it does, he receives the full amount of toll arising from the whole passage, and receipts it on the bill, which he copies into a book provided by him for that purpose; after which, the bill, with the receipt, is handed back to the boatman, who, when he arrives at the next place of collection, exhibits his receipted bill to the collector, and if there has been no change in the lading, is permitted to continue his passage. If additional articles are taken into the canal, between the first collector, to whom the bill of lading is presented, and any subsequent one, such subsequent collector ascertains whether all such articles are properly added to the bill, and makes the same receipt of toll and entry of those articles, as was made by the first collector in relation to the original bill. The collectors are required to give bonds for the faithful discharge of their duty. And by way of a check upon their accounts, one of them is required to make an entry of all the property paying toll, at the several places of collection, and of all the receipts therefor, by the collectors. The system further proposes, that once in three months an agent of the canal commissioners, who is competent to the task, shall examine the books of the several collectors, for the purpose of ascertaining their accuracy; receive from them the amount of tolls collected during the preceding quarter, and transmit it to the commissmissioners of the canal fund.

During the last year the construction of the eastern section of the Erie canal has been commenced: and thirty miles of the line, beginning at the termination of the middle section, at Utica, and extending along the valley of the Mohawk, eastwardly of the Little falls, to the town of Minden, is now in such a state of forwardness as to ensure its entire completion the present year.

The original surveys on this section, which were extended eastwardly as far as the Schoharie creek, having pointed out a practicable route for the canal, without marking the precise line which was to be followed, the engineers, on the opening of the last season, were required to re-survey the route, and definitively to locate the line; and, at the same time, to lay it off into half mile sections, that it might be put into the hands of the labourers as early as possible. The line embraced many places of difficulty, and admitting of many variations in its course, much time was necessarily spent, in ascertaining and determining on the best possible location of it; and nearly half of the season had elapsed before the most considerable part of the work could be put under contract. The contractors, however, commenced their work with alacrity, and continued to push it with great vigour, until the approach of winter, when the entire expenditure of the money appropriated to the construction of this section, as well as the inclemency of the season, necessarily suspended their labours.

During the time which has been allowed for active operations, some of the most considerable and arduous undertakings on the line, have been performed: and every part of the work, which it was important to have done the last season, has been accomplished. Eight miles connected with the Rome level, is so far complete as to require nothing more to render it navigable than the filling up of the drains, which were left open for the security of the newly formed banks, which, without this precaution, would have been liable to injury, from the sudden admission of heavy floods of water into the canal. On the remaining twenty-two miles, all the grubbing and clearing is completed, and a considerable proportion of the excavation and embankment.

An important work has been executed, at the dug way, opposite the village of Herkimer, where a steep and sliding hill on one side, and the Mohawk river on the other, has barely allowed room for a road to be formed between them. At this place, to preserve the road, and to avoid the falling earth from the hill, it was necessary to construct the canal along the edge of the river, by carrying in the Mohawk a broad and high embankment of earth taken from the hill. This has been done; and the whole has been supported and protected, from the injurious effect of a strong current, by a substantial wall of stone, laid up, from the bottom of the river to the top of the embankment.

At the Little falls, the spirited exertions of the contractors have been attended with great success; and on two sections, which included what has been considered the most difficult part of the work, and as requiring the labour of years to perform, the whole excavation is already nearly completed; and from the massy fragments of rock, which have been blown from the line of the canal, a broad and substantial wall has been built, which, forming and supporting one side of the canal, extends along the margin of the river for near three quarters of a mile, and rises to a line measuring from ten to twenty-five feet above its base. Besides these two sections, there are three sections above, and one below the falls, on which a good deal of rock has been encountered. A part of it has been thrown out, and what remains to be done can be executed before the termination of the ensuing summer.

From Utica to Minden there is a fall, in the canal line, of one hundred and five feet, which will be descended by thirteen locks. For these, contracts have been entered into, for their completion early in September next. And nearly all the stone necessary for their construction, consisting of the finest and largest blocks of lime stone, have been quarried, hewed, and transported to the line of the canal, and are in readiness to be laid into the works on the opening of spring.

Of six aqueducts and thirty-six culverts, which are required, on the line now under contract, the greatest part of them have been built, with stone laid in water cement, and are completed, in the most substantial and durable manner.

Contracts for the performance of every work have been obtained, on terms extremely favourable to the state. And it is a most interesting fact, that notwithstanding this part of the canal includes the expensive work, at the Little falls, the most formidable obstacle on the eastern section, and also includes more than one half of the lockage, between Utica and Schenectady, the whole will be completed, at an expense, per mile, but little exceeding that of the middle section.

From Minden, the survey of the route of the canal was continued along the south side of the Mohawk to the head of Cohoes falls. At this point, the engineer found the first and only practicable place of leaving the valley of the Mohawk, and of descending, with the canal line, to the Hudson. The lateness of the season, and the necessity of his returning to put the line west of Schenectady in a situation to be put under contract, before the setting in of winter, prevented his prosecuting his surveys and examinations as far as, under other circumstances, would have been advisable. But this examination has been such, as to warrant the conclusion, that the canal can be constructed, along this route, at an expense much within the original estimates.

The important services pertaining to the engineer's department on the eastern section have been, for the last season, chiefly devolved upon Canvass White, Esq.

whose usefulness, from the beginning, has been constantly increasing with the progress of our labours, by his continued assiduity and increasing knowledge.

The Erie canal now affords an artificial navigation of about ninety-eight miles in length, including the Salina side-cut. And we confidently expect to double that distance before our next annual report. With the wise and liberal appropriations, which your honourable body has lately made applicable to the undertaking, it is not unreasonable to anticipate the full consummation of the project, for connecting the great lakes of the west with the Atlantic ocean, before the close of the year 1823.

The works on the Champlain canal have been vigorously prosecuted during the past season. About seventeen miles of excavation, extending from Saratoga falls to within ten miles of the village of Waterford, have been nearly completed. The banks of the canal, on the above seventeen miles, have been formed and completed with a strength and beauty far surpassing any of the similar works which had been previously finished; and it is but justice to attribute this improvement in the permanency and symmetry of the work to the skill, fidelity, and industry of William Jerome, Esq. the assistant engineer, to whose superintendance the above mentioned excavation was principally committed. The aqueduct across Fish creek is under contract, and the materials for its construction are nearly all delivered. Contracts have also been made for the waste wiers, bridges, &c. and for fencing the canal, which are in part executed. A dam has been thrown across the Hudson, at the head of Fort Miller falls, which, aided by excavations made in the bed of the river, through Crocker's and Potter's rifts, has produced a good boat navigation between fort Edward and fort Miller. The excavation of a lateral canal around fort Miller falls, and the construction of two locks at that place, are in a state of considerable forwardness. The greater part of the materials for a dam across the Hudson, to be located near the head of Saratoga falls, are prepared. The object of this dam is to raise the water into the canal on the Saratoga level, and to complete the navigation above the dam, to its junction with the lateral canal before mentioned. The fencing of the canal, and the completion of the towing path along Wood creek, between fort Edward and Whitehall, have been nearly finished; and that part of the route in which the navigation is confined to Wood creek, has been very much improved by cutting off several sinuosities in this stream.

The unparalleled drought of last season occasioned, for three months, a deficiency of water on the summit level. Although it could not be predicted that such a season would occur, yet its result, if it did happen, was always foreseen. Indeed, from the examinations of 1816, it was not believed that the summit level could be navigated at all without a supply of water from a feeder. It was supposed at that time, that a feeder might be brought from lake George, or from the Hudson river; and it was ascertained, that one might be easily made from Halfway brook: and in the report of the canal commissioners of the 18th March, 1817, it is proposed "to erect a dam across Halfway brook, of eighteen feet in height, half a mile above the mouth of said brook, and by a natural ravine leading to the south, to direct so much of the water of said brook to the summit level, as may be necessary for the convenience of the canal."

Further examinations were made in 1817, and in the report of the 31st January, 1818, the canal commissioners state, that "considerable time was spent in exploring, with a view to ascertain whether, in case the trade on the canal should, in a course of years, increase to such a degree as to exhaust Halfway brook, which is the principal source of supply for the summit level, a sufficient quantity of water might be obtained from any other quarter. Levels were carried from the Hudson river, at several points above fort Edward, to the line of the canal. And it was ascertained, that, in the event of future deficiency, water may be drawn from the Hudson by a short feeder, in any quantity which may be necessary." Thus it will be perceived that Halfway brook was regarded as "the principal source of supply for tho summit level," that a feeder from this stream was deemed indispensable, and that the necessity of an additional future supply from the Hudson was also anticipated.

The summit level was finished in 1819, and it was found, during the excavation of the same, that several copious springs were intercepted, and that without any feeder the supply of water was greater than had previously been expected. By a reference to the report of the 18th Febuary, 1820, it will be seen that it was expected, "that with ordinary seasons" a feeder for the present would not be wanted. The limited appropriations to the Champlain canal did not warrant the construction of a feeder in 1819. Had the feeder been made, the summit level could not have been finished: and it appears in the same report, that "owing to a deficiency of funds the canal was not fenced."

For ten years previous to the last season, the summers in general were cool and wet; and during the whole of that period, (except the season of 1816, had the canal been previously constructed, it is believed there would have been a sufficient supply of water on the summit level, without any aid from the Hudson, or Halfway brook. But last summer was an exception to almost every other. From the middle of June to the 20th September, the ordinary summer showers were almost entirely wanting: and during this period, the heat of the atmosphere occasioned an evaporation so intense as to exhaust the streams and springs in the neighbourhood of the Champlain canal, to a degree never before witnessed by the oldest inhabitants of the country.

The foregoing references to former reports, and the preceding observations, are submitted, to show that the failure of water on the summit level was not occasioned by any mistake of the commissioners or engineer, or by leaks in the canal, as some have erroneously supposed.

The extraordinary dryness of the last summer produced a considerable diminution of the water of Halfway brook, although that stream is entirely formed by springs: and as such seasons may occur again, it was thought best to make a feeder from the Hudson in the first instance, whereby the expense of a feeder from Halfway brook, which might not at all times be sufficient, would be entirely saved to the state.

Two modes of constructing this feeder presented themselves. The one, by taking the water from the head of Baker's falls, and leading it along the declivity, parallel to the river, to a point where the bank, composed of slate rock, became too precipitous to proceed further, and from thence by a small tunnel or sough, nearly at right angles with the river, to conduct the water through a ridge of slate into a ravine, from whence it might easily be connected with the summit level. The other, by throwing a dam across the Hudson, about half a mile above the village of fort Edward, thereby raising the water to the necessary height, and by a navigable cut of about half a mile in length, to connect the pond created by said dam with the summit level. This feeder is indicated on the engraved map and profile of the Champlain canal.

It was at first thought, that the former mode might be preferable to the latter: but, after spending some time in sinking shafts for the sough, the hardness of the rock, and the great influx of water through the seams of slate produced a different conclusion. A contract was therefore made, for the erection of the dam, the excavation of a navigable feeder, and the construction of a guard-lock, to prevent the irruption into the canal of the floods of the river. The excavation was nearly finished last season, and the materials for the dam are to be transported to the spot early in the spring. With a favourable season, it is expected that these works will be finished within six or seven months from this time. It is believed, that the Champlain canal will be completed and rendered navigable next season, as far as the south end of the Saratoga level, and that the remaining ten miles, to the village of Waterford, will be excavated. The whole of the Champlain canal might be finished this year, with the aid of the liberal appropriations recently made by the legislature. But as there is ninety-three feet of lockage in the above mentioned ten miles, and as the stone for the locks must be brought from the town of Kingsbury, it will be more economical to delay the construction of the locks until another year, when the canal will be in operation, as above mentioned, and thereby save the expense of about thirty miles of land carriage of these ponderous materials.

Although the navigation was interrupted for three months, by a deficiency of water on the summit level, yet, during the spring and fall, considerable quantities of lumber were transported through the canal, from lake Champlain to the Hudson, and from thence to a southern market; upon which, however, as the works were not finished, no toll was received.

The whole quantity of lumber, which passed from lake Champlain, through the locks at Whitehall, according to the return of the lock-keeper, is as follows, to wit: one hundred and fifty-nine thousand boards, ninety-eight thousand plank, thirteen thousand cubic feet of pine timber, ten thousand ditto of hemlock timber, twenty-nine cords of tanner's bark, twenty four ditto. of fire wood, one hundred and four thousand oak staves, forty-nine thousand shingles, three thousand four hundred and eighty saw-logs, ten thousand rails, nine thousand cedar posts, and eight thousand fence boards.

In looking back to the numerous difficulties, and responsibilities, some of them on an aspect the most disheartening, which surrounded the canals, especially in their commencement, we feel compelled, by common justice, to commend the aid, which has been, at all times, afforded by our engineers. In the selection of all the persons, who are now employed by us, under this character, we have been eminently fortunate. But to the Hon. Benjamin Wright and James Geddes, the state is most indebted. Possessing most local information, competent science, long experience in many kinds of business bearing some analogy to canal operations, and well established characters for industry and fidelity, these gentlemen have rendered the most essential services, in all the duties of their department. They were first appointed engineers: they have unceasingly, and with improving fitness, devoted their best faculties to the great cause in which they were engaged. And they have hitherto been found equal to the high trusts confided to them.

The state has now been engaged, nearly four years, in the actual construction of the Erie and Champlain canals. And the success of her efforts has been, at least, equal to the expectation of the most ardent advocates of these measures. This success could not have been attained, without care, vigilance, discretion, and energy, in the complicated and arduous labours of which it is the fruit. And these labours could not have been performed, without the support of a wise foresight and just liberality, in several successive legislatures. To us it appears, that these legislatures have afforded a spectacle most animating, encouraging and delightful, in reference to the sagacity of the people to understand, and their wisdom to provide for, their most substantial interests. They exhibit the most impressive example which the United States have yet produced, since the adoption of the federal constitution, of the beneficent effects of free government upon the character of a community. They are intimately connected with the best hopes of the republic. Rising above all fugitive and partial interests, and with a full detail of the costs of these works before them, the immediate representatives of the people have so clearly discerned the benefits which they would introduce, as to apply to them, from year to year, a greater proportion of their funds, than is sufficient to defray the ordinary expenses of their state government. And this proportion, your honourable body has greatly increased.

When a project is once decisively embraced, of which the practicability is ascertained, but of which only a small part of its advantages can be enjoyed before it is fully performed, it is wise, it is economical, to apply large means to the performance. And the appropriation of the additional million of dollars to the canals, for this year and the next, will be every where a theme of praise and congratulation. This act of the legislature is a just and great cause for rejoicing, because it ensures the speediest possible completion of the canal; because, when they are completed, they will immediately communicate their blessings to millions of freemen; and because they will contribute most effectually and rapidly to the spreading of our fellow-citizens broadcast and thick, with all their precious institutions for the perpetuation of civil liberty, and the promotion of knowledge and virtue; with every thing most desirable and sacred, in our social condition, throughout the almost boundless and unoccupied regions of the west."*

The valley of the Hudson rises by a more gradual acclivity than does that of the Mohawk. From the level of low tide in the Hudson river to a point on that stream 1¼ mile above Waterford, the bed of the river rises about 35 feet, to render which passable, 5 locks are designed. Ascending 8¾ miles higher to a point between the mouth of Anthony's kill and Hoosack river, another rise of nearly 53 feet takes place, in which distance, the construction of 7 locks is contemplated.

These 12 locks and 88 feet attain a summit, upon

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[*] Haines, p. 450.

which the canal will be carried 18 miles on one level to the falls, at fort Miller. Here a rise of 16 feet is overcome by two locks. A dam above these locks and falls again produces a slack water of 16 miles to another fall at fort Edward. By 4 locks, and 36 feet ascent, the elevation of 140 feet, on the summit level between lake Champlain and Hudson's river, is attained. Along this summit level, the canal is cut 12 miles, to Cape Anne upon Wood creek branch of Pawlett river, flowing into lake Champlain.

At Cape Anne, the slope commences towards lake Champlain, and by a rapid depression of 26½ feet, and 3 locks, reaches another level 12 miles in length, reaching Whitehall at the mouth of Pawlet river. At the latter place 3 more locks descends 26 feet into lake Champlain.

The Champlain canal is nearly completed; it is indeed already navigable, but, contrary to the opinion of the commissioners in their report of January 31st, 1818,[*] it is now found necessary to introduce a feeder from the Hudson, above Glen's falls, and as this source will be above the summit level, every section of the canal will be amply supplied.

By a resolution of the board of commissioners in 1818, the Erie canal was extended to 40 feet width at the surface, 28 at the bottom, and 4 feet deep of water. The locks were to be made 14 feet wide and 90 long in the clear. By a subsequent order of the board similar dimensions were given to the canal and locks, between Albany and lake Champlain.[†]

It is now confidently calculated that a complete inland navigation in the entire extent of both canals will be effected before the close of 1823.

In some instances, from the nature of the document, round numbers have been necessarily used, but, we believe, not to any extent which can very seriously affect the general correctness of the statement. The importance of the subject has rendered some amplification necessary.

Table of the area of those parts of the United States and Canada, which will most certainly be opened to the commerce of the Hudson by the completion of the two New-York Canals.

	Square miles.
Basin of Champlain,	5,000
United basins of Oswego and Seneca rivers	7,500
Basin of Erie	27,000
Basin of Michigan	60,000
Basin of St. Clair	7,800
Basin of Huron and Nipising	40,000
Basin of Superior	90,000
	236,300
From which deduct for water,	
Lake Champlain	1,100
Small lakes in the basins of Genesee and Oswego	240
Lake Erie	15,750
Lake St. Clair	750
Lake Huron	13,000
Lake Michigan	13,500
Lake Nipising	800
Lake Superior	30,000
Smaller lakes and rivers	2,000
	70,140
Remains for land	166,160

Amounting to 111,129,600 acres.

This expanse nearly equals four times the superficies of the state of New-York. Though more than one-third of the space we are surveying is in Canada, it may be here correctly included, as the course of commerce will be but little influenced by national boundaries.

Next to the Grand canals of New-York, we have to notice the projected canal from the Rariton to Delaware river. However, as no ostensive steps have yet been taken to effect the New-Jersey canal, it will be unnecessary to enter into much detail on the subject.

Surveys and levels have been taken with so much accuracy, as to ascertain the practicability of executing a navigable canal over New-Jersey, and a company has long since been incorporated for that purpose. The points intended to be united are, Trenton on the Delaware, and New-Brunswick on the Rariton. The route was traced by following the Assampink to near its source, and thence by a short cut into Stoney brook, a branch of Millstone river, and down the latter and Rariton to tide water. The very erroneous principle adopted of following the natural channels, has tended to discredit the operations of the New-Jersey canal company.

The distance from Brunswick to Trenton is about 26 miles, and the highest intermediate summit level 50 feet, between the Assampink and Stoney brook. It is supposed, however, that a summit level but little exceeding 40 feet can be obtained, by cutting between the confluence of Assampink and Shippetankin creeks, and Rowley's mill, near the confluence of Stoney brook and Millstone river.

An adequate supply of water can be drawn by short feeders from Philip's springs, Trenton creek, Stoney brook, and Millstone river, all of which are more elevated than the route of the canal, some intermediate sand hills excepted. Sufficient depth of water for a sloop navigation exists at the two intended extremities of the intended canal.

Estimated expenses:

Digging 28 miles, at 20,000 dollars per mile	$560,000
Lockage, 100 feet, probably less, at 1,250 dollars per foot	125,000
Feeders, purchase of land, and water rights	115,000
	$800,000[‡]

Upon the importance of the New-Jersey canal but one opinion can exist, but as respects the expenses, it may be doubted whether less than one million of dollars could suffice to effect such an object.

If such an inland communication did exist, it is probable, however, that if the intended transmission of coal from the Lehigh and Delaware rivers succeeds, and there is no rational doubt of such success, that such a coal trade alone would, besides the incidental expenses of repairs and superintendance, produce a revenue of more than the interest of $1,000,000.

Though, comparatively, little has been done by Pennsylvania, Delaware, and Maryland, in meliorating the natural inland water communications of these states respectively, yet considerable has been performed, particularly by Pennsylvania, and much designed by all to give efficiency to canal connexions between the various rivers and bays which intersect the country occupied by these three states. From some recent and favourable symptoms, we are warranted in indulging the belief, that the system of canal and lock navigation will occupy, in future, no small share of the domestic exertion and legislative policy of states, whose waters are so pre-eminently capable of improvement.

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[*] Haines, p. 288.

[†] Haines, p. 364.

[‡] Gallatin's Report.

The canal improvements made or designed in Pennsylvania cannot be better prefaced than by the following table, extracted from Mr. Condy Raguet's report on roads, bridges, and canals, made to the legislature of that state, March 23d, 1822. It may, however, be premised, that this report does not include any notice of the act of the legislature of Pennsylvania, of Feb. 13th, 1822, granting corporate powers to the Lehigh Coal and Navigation Company for the improvement of the navigable waters of the Lehigh.

List of the canal and lock navigation companies which have been organized, showing the time at which the works were commenced, and at which they are expected to be completed, the extent of the improvements contemplated, the proportion which it is expected will be of canals, the amount of individual and state subscriptions, original price of the shares, the number of feet of falls to be overcome, the expected cost of the whole improvement, and the progress which has been made in the works.

Works when commenced.	Names of Companies.	Extent of improvements.	Expected proportion of canals.	Individual subscriptions to capital stock.	State subscription to capital stock.	Original price of shares.	No. of feet of fall to be overcome.	When expected to be completed.	The cost or expected cost of the improvement.
		Miles.	Miles.						
1792.	Schuylkill and Susquehanna Navigation[1]								
1793.	Delaware and Schuylkill Navigation[2]								
1814.	Conewago Canal, east side of the river[3]	1¼	1¼	private property	nothing		21	completed	120,000
	Lehigh Navigation[4]								
1821.	Union Canal[5]	71	nearly all	450,000	50,000	200	510	1825	800,000 to 1,000,000
1816.	Schuykill Navigation[6]	117	59	948,150	50,000	30	610	1823	950,000 to 1,000,000
1821.	Monongahela Navigation[7]	90	not known	18,360	30,000		60	not known	
1818.	Lehigh to be rendered navigable by White and Co.[8]	80	none		nothing		1,184		
1821.	Conestogo to be rendered navigable by James Hopkins[9]	18	the whole slackwater	private	nothing		70		
	Conewago Canal, west side of the river[10]	1	1	ditto	nothing		21		100,000
				1,416,510	130,000				

We briefly notice each of those canals, or other intended inland water improvements, advancing from north-east to south-west, and commencing with the Lehigh.

The contemplated navigation of the Lehigh has, for its principal object, the supply of Philadelphia, and other places, with coal. As the mode of navigating this stream is a departure from the ordinary manner, (by canals and gate-locks,) some explanation is necessary, both of the peculiar features of the river, and of the plans pursued by Mr. Josiah White, the engineer.

The Lehigh rises in Wayne, Luzerne, and Northampton counties, in the high mountain valleys; flows to the south-west, by a number of creeks, about 30 miles, and, uniting near the north-west part of Northampton, turns south 25 miles to Lausanne. At the latter place it agains turns to south-east by south, 35 miles to the foot of the Blue ridge, at Allentown, where, forced from its course by the latter mountain, the Lehigh once more curves, and, assuming a north-east course of 25 miles, falls into the Delaware at Easton. These distances are given by comparative courses; the actual bends of the stream amount to, perhaps, one-third more. The following elevations, supplied to the writer of this article by Mr. Josiah White, will serve to show the rapid descent of this little river:

	Miles.	Feet fall.
From Stoddartsville to Nesquehoning,	35	845
Nesquehoning to the Gap, . .	15	160
Gap to Easton, ...	30	205
	70	1210

Nesquehoning creek falls into the Lehigh 1½ mile above Mauch-chunk creek, the outlet to the coal mines. The latter is therefore about 45½ miles, by the bends of the river above Easton.

Attempts will soon be made to improve the navigation of the Lehigh river, above the outlet of the coal mines. From Stoddartsville, the river flows down the mountain valleys some distance through a hilly region, and thence in an immense ravine, having mountains, rising to 1000 or 1500 feet along each bank, and, in most places, no space left between the impending steeps but the mere breadth of the stream. The creeks which enter from both banks are similar to the river, flowing also along very deep mountain-limited vales.

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[1] These two companies, after the expenditure of a large sum in abortive undertakings, became united in 1811, under the title of The Union Canal Company.'

[2] Two dams of 800 and 500 feet, 1 guard and 3 ascending and descending locks, each 110 feet in length, 18 feet wide, and 7 feet deep.

[3] Nothing was ever done by this company.

[4] The private property of James Hopkins.

[5] The canal on the summit level laid out, and the execution of the work contracted for.

[6] 23 dams, 23 guard and 54 chamberlocks, and 24 miles of canal finished, and 22 miles of canal to be finished by November, 1822.

[7] In the summer of 1821, a channel was commenced at the Brownsville ripple—Expenditure about $500.

[8] Considerable improvements have been made by these individuals between Lausanne and Easton, but the extent is not known.

[9] Taking a level of 12 miles, in which the ascent was 60 feet.

[10] Completed many years ago; no particulars ascertained.

Mauch-chunk creek rises between two of those mountain ridges, and, flowing nearly east, falls into the Lehigh, at North Lat. 40° 51′, and 0° 36′ West Long. from Philadelphia, after a course of about 10 or 11 miles. The fall in 1½ mile from the mouth of Nesquehoning, to that of Mauch-chunk, is probably about 18 feet, which, taken from 365, leaves 347, as the fall from the latter place to Easton. From the head of tide water in Delaware, to Easton, in a distance of 50 miles, it is probable that river falls 200 feet, which sum added to 320, gives 520 as the elevation of the mouth of Mauch-chunk creek above tide water.

The coal mine from which that mineral is designed to be drawn for market, is again elevated 1006 feet above the mouth of Mauch-chunk; therefore, the coal must be lowered 1526 feet before reaching the surface of the Delaware tides.

The engineers have planned and constructed a road, winding first 2 miles up the vale of Mauch-chunk creek, and then gradually up the mountain side 7 more miles, to the coal mine, or, much more correctly, coal bed. This road is certainly amongst the finest specimens of that kind of improvement yet produced in the United States. The condition of the valley of Mauch-chunk, and that of the impending mountain, in a state of nature, was, in a peculiar degree, appalling to any mind intent on the formation of a road. The mountain masses are here formed of a coarse Breccia, or silicious puddingstone, of all degrees of compactness, from a close grained rock, approaching the aspect of *grauwacke*, to that of imbedded pebbles, of considerable size. This rock formation, broken into amorphous fragments, from the weight of perhaps 150 tons to that of a finger stone, lies rudely heaped along the valley, and hanging from the mountain sides.

Through this heavy and unmanageable mass, however, a road of 9 miles in length has been made, sufficiently wide for two carriages to be driven past each other, and as perfectly smooth as any pebble road to be found on Long Island, or any other parts of the sea-sand alluvial border of the United States. This road has excited at once delight and astonishment in the minds of every person who has travelled over it to the coal mine, and affords, with the attendant scenery, a most delightful ride. For the objects, however, embraced in this article, it is the facility it gives of transporting coal to a navigable stream which constitutes its chief interest.

We have already stated that 7 miles only were along the slope of the mountain, and that the mountain was 1006 feet above the surface of the Lehigh, at the mouth of Mauch-chunk creek. In 7 miles there are 36,960 feet, and there is only an ascent of about 1½ degrees. The road is so regularly and so skilfully conducted, as to render so gentle an acclivity entirely imperceptible to the eye, and a carriage is drawn up, with no more apparent difficulty than down the mountain side. A common team of four oxen will, with perfect ease, haul 5 tons of coal to the landing, and could draw much more, if the lower two miles were not on a level, or nearly so.

The coal lies in an enormous mass, of unknown depth and extent, upon the very apex of the mountain. It is quarried out with as much ease as ordinary stone from a bank. The incumbent clay, stone, and other matter, are taken away, and the bed of pure coal exposed to full view. The waggons, or carts, are backed through a gallery upon the mineral, which is thrown into the vehicle from its original position. The entire load cannot, however, be taken immediately from the mine, from some rising ground intervening between the mine and the summit level of the road. The acclivity is even here, nevertheless, so little, that more than an ordinary waggon load can be drawn from the centre of the mine to the bank of the Lehigh.

We may therefore consider the necessary improvements to transport the coal to the water as already complete; and, as far as a judgment can be formed from present appearances, the supply inexhaustible.

The Lehigh, like all mountain streams, flows over alternate ponds and rapids, and above the water gap, or passage of the river through the Kittatinny mountain, as we have already observed, between impending rocky slopes or precipices. From the mouth of Mauch-chunk creek to near the village of Lehighton, or about 4 miles, no natural bottom existed. A good road has been formed along the right bank, cut out of the mountain side. The river is in this space found winding through a deep valley, along which, without enormous expense, no canal could possibly be constructed. At Lehighton, bottoms spread, but are again interrupted by approaching precipices, which continue, with more or less magnitude, to the Delaware river.

To render this stream navigable, the engineers (White and Hazard) have adopted the principle of dams and falling locks. Their dams commence at Mauch-chunk, and continue, where necessary, as far down as Easton. The dams are of two kinds: one consists merely of two wings, confining the water to a mid-channel. These are used to pass over shallows. The second are real breast dams, formed of wood and stone, with side locks. Of the latter, 10 have been built, 5 between Lehighton and Mauch-chunk, 4 between Lehighton and the Gap, and 1 at the Slates, near Kreidersville.

The Lehigh falling locks are peculiar to that river, and are the invention of Mr. Josiah White. No verbal description could suffice to give to those, who have not seen them in operation, any adequate idea of their construction. Unlike the common gate lock, opening sideways, the Lehigh locks are formed to fall, and suffer the sluice of water to rush over. They open and shut, or, more correctly, rise and fall, by the pressure of the water let in underneath, by a very simple process, managed by a lever. A single ordinary boy, of 12 or 13 years of age, has sufficient strength to turn the lever, and either open or close these locks at will. Three or four feet water is let over for the purposes of navigation. The severe freshet of the spring of 1822, has not produced any more effect upon the falling than the upright locks; the dams have also withstood the pressure of the water and ice, without any particular damage being sustained.

That the system is well founded, we have no doubt, of using rivers, the channels of which are very circuitous and interrupted by shoals, rapids, or falls, as the feeders of canals, rather than use the stream itself for navigable purposes. But to this excellent general rule the Lehigh is, perhaps, as remarkable an exception as could be selected to justify a contrary course of proceeding. Rock, and even in some measure mountain bound in all its length, no abridgment of distance of any considerable amount could be gained along its banks, admitting such a work practicable and executed. The amount of produce also to be transported by its means consisting almost exclusively of so heavy a material as coal, exceeding, it is probable, in bulk and weight, 1000 to 1, of what will ever be necessary to carry up against the stream. The transportation of grain and other articles from Lehigh county below the gap, is subject to a similar observation made respecting coal; the great mass from the latter section must be also a down stream transportation. Therefore, if the mode of dams and falling locks can be rendered adequate to the free emission of coal and other bulky articles, and made permanent against the vicissitudes of the river, then its adoption is fully justified, and more particularly so, when the superior cheapness of the method adopted is taken into view. The respective merits of the two systems are in a fair way of being fully tested, as one is carried into effect on the Lehigh, and the other on the Schuylkill.

We cannot quit this part of our subject, without making some observations upon the coal of Lehigh and Schuylkill in general. The coal of those streams is of that species called Anthracite, without bitumen, kindles with some difficulty, but burns with a most intense heat. It is the safest of all known fuel, as it consumes almost without flame, and entirely without the emission of sparks, and if one of the ignited fragments falls separate from the mass in the fire, it instantly extinguishes. Its respective cheapness, at 30 cents per bushel, when compared to common good oak wood, at five dollars per cord, fire places suitable to each kind of fuel being adopted, is supposed to be as 2 to 1, in favour of coal. How far it is calculated for manufactories, or steam boats, we are unprepared to determine. Let the merit of the Anthracite coal, as an object of domestic use, be what it may, it can be supplied, when the two branches of Delaware are rendered navigable, to any amount commensurate with public demand.

Transported to market through either the Schuylkill or Lehigh channels, the mines of that mineral hitherto discovered, and within reach of either stream, lie scattered through the intervening country. Imbedded at different depths, and found in masses of great variety of extent, very different must be the expense of extraction and conveyance to the respective navigable waters. The writer of this article visited the coal mines in the month of September 1821, proceeding from Mauch-chunk, on the Lehigh, to the neighbourhood of Orwicksburg, on the Schuylkill. It is, therefore, from personal observation that most of the facts are stated respecting the locality of those mines. From the geographical position of the Lehigh, it is a considerable stream when it reaches the vicinity of the coal, and can therefore be rendered navigable nearer some of the most abundant mines than can any branch of the Schuylkill. But the very extensive mine now in possession of White and Hazard, and their associates, though its stores of mineral are brought to market by the Lehigh channel, is, nevertheless, situated on the dividing point between the waters of the Schuylkill and Lehigh.

Indications of coal are frequently found in places where no effective operation to extract the mineral have yet been made. Indeed, every year adds weight to the former testimony, of the boundless resources of that fuel, within an accessible distance from the waters of both these rivers.

By an act of the legislature of Pennsylvania, of February 13th, 1822, the Lehigh Coal and Navigation Company was incorporated. They are bound, by the act of incorporation, to complete a down stream navigation in the Lehigh, from the mouth of the Nesqeuhoning to Easton, in 1824, consisting of 18 inches in depth, and 20 feet in width. And from Stoddartsville to the mouth of Nesquehoning, in 1838, of a similar nature with that from the Nesquehoning to Easton.

Union Canal.

The present advance of the Union Canal Company, and the origin of that corporation, are shown briefly in the prefixed table, but the following historical notice cannot be irrelevant. It is extracted from views of the roads and canals of Pennsylvania, by William J. Duane, Esq. and published in 1811.

"In the year 1789, various and judicious plans were proposed to the legislature, for improving the state, by a variety of intelligent and patriotic citizens, to the labours of which I have heretofore with pleasure alluded. At the instance of this society, commissioners were appointed by law, in 1790, to explore the several routes proposed for a communication between the Delaware and the lakes; they were instructed to report upon the practicability, the best route, and the expense. The commissioners performed this duty promptly, and reported, 1st. That a communication was practicable; 2d. That the best route was by the Juniata, or that which in my last letter I designated as *the southern;* 3d. That all the intervening rivers could be cleared and opened, for about 108,000 dollars.

The legislature, paying credit to the commissioners, and being aware of the importance of such a route, determined to commence it in that quarter, which it was supposed offered the greatest obstacle and promised the greatest advantages. Hence originated the incorporation of two companies, whose proceedings it is necessary to mention.

The Schuylkill and Susquehanna Company was incorporated in 1791, with a capital of 400,000 dollars, for opening a canal communication between the Schuylkill and Susquehanna rivers, by the following route; from Reading on the Schuylkill, by the Tulpehocken creek, to Myer's town, 37 miles; from Myer's town to Lebanon, the summit level, by a canal, 4; from Lebanon to the Swatara creek, 15; down the Swatara to the Susquehanna, 23; in all 79 miles.

The Delaware and Schuylkill Company was incorporated the year following, 1792, with a capital also of 400,000 dollars, for opening a canal from Philadelphia along the east bank of the Schuylkill, 16 miles, to Norristown.

The legislature declared, as the principal object of both these works, the opening a communication between the eastern and western waters.

As soon as these companies were organized, committees were appointed by them to superintend the commencement of the respective works. Unfortunately there was no engineer at that time in Pennsylvania competent to aid the committees; they therefore sent to England, and engaged Mr. William Weston, a celebrated engineer, to come out and manage both works. In the mean time the committees did not think it proper to remain idle, they commenced the respective undertaking, and had each in considerable forwardness, when Mr. Weston arrived, in January, 1793. This gentleman immediately proceeded to examine the work done by the Susquehanna company, at Lebanon canal, and reported—"From such a view as the time and season of the year would permit me take of the canal through the middle ground near Lebanon, I have little doubt but the most favourable line has been adopted." He also examined the Delaware and Schuylkill canal, and reported generally, "it appears to be judiciously laid out."

Experience has proven, however, that it would have been much better, if the companies had not commenced any of the works, until Mr. Weston had had full time to make every necessary inquiry, for after Mr. Weston had an opportunity to judge accurately, he recommended alterations in both the plans originally projected, upon which the companies had commenced. This was the first obstacle to the work, and one of the causes of its ultimate decline.

During the whole of the year 1793, Mr. Weston devoted his attention to both canals, and in January, 1794, made a detailed report respecting them. With respect to the Schuylkill and Susquehanna communication, he said, 1st. That the unerring test of experience had proven the inefficacy of such a place as the company had originally adopted, namely, the making a water communication by the beds of the Tulpehocken, Quitapahilla, and Swatara; 2d. That a canal, 70 miles in length, from the Schuylkill to the Susquehanna, chiefly along the banks of the Tulpehocken and Quitapahilla, would be infinitely preferable; 3d. That the expense of completing the work upon this plan would be, in addition to the 400,000 dollars already subscribed, 821,330 dollars and 60 cents. Having submitted this statement to the company, Mr. Weston left it to their discretion, in what way to proceed.

The company were soon convinced of the soundness of Mr. Weston's advice, and accordingly they presented a memorial to the legislature, setting forth:

1st. The Susquehanna and Schuylkill canal is the greatest link in the chain that is to connect the eastern and western waters.

2d. The summit level of this canal, for upwards of four miles, is completed, in respect to the heavy digging, and the purchase of all the ground for the site of the canal, the locks, and towing paths; as well as the grounds containing the sources and springs of the waters, and through which they are to be conducted into the reservoir at the summit level. The final amount of expenditures on this part will be 106,666 dollars and 60 cents.

3d. We approve Mr. Weston's plan of a canal, instead of making use of the beds of the creeks; and as the original capital will not pay more than one-third of the whole expense, we pray legislative aid, by a loan of a sufficient sum upon interest, so as to enable us to finish the work.

The company, anticipating legislative aid, continued the work under the guidance of Mr. Weston, during the whole of the year 1794. In December of that year, that gentleman made a report, from which I quote these interesting parts:

"I flatter myself that the progress made on the works, in the short space of seven months, will prove satisfactory to the board. On a careful comparison of the actual state of the various works, and an ample allowance for the completion of such parts as remain unfinished, with the previous estimate laid before the board in my last report, it appears, that from the east end of the summit-level to Michael Kreitzer's plantation, a distance of more than four miles and a quarter, the actual expenditure will fall short of the estimated one at least eight thousand dollars. Though I would not wish to appear too sanguine, yet I may be allowed to draw favourable inferences of the remainder of the line: independent of this, I have well founded reasons for asserting, that the works will rather proportionably diminish than increase in expense, as the important object of land-carriage will, after the ensuing year, in a great measure, be done away, by the canal being made subservient to that purpose.

From the difficulty of procuring waggons to haul bricks, lime, &c. I could not employ half the number of bricklayers I had at first contemplated; yet more work has been done in four months, than is generally executed on most canals in one season. Five locks of six feet fall, and two road bridges are completed; and such progress made in the sixth lock and two more bridges, that a fortnight's work in the coming spring will suffice to finish them."

Such was the flattering account of this important work at the close of 1794; yet in this state it was suspended, and has not since been improved.

Having thus briefly noticed the rise and fall of this undertaking between the Schuylkil and Susquehanna, I will take a similar review of the Delaware and Schuylkill canal.

In less than three months after his arrival, Mr. Weston made a report upon this canal; it was highly flattering: in December, 1794, he made another report, in which he said; 1st. That one-third of the work, above five miles, was finished, and that contracts were formed and forming for a vigorous prosecution of the remainder: 2d. That the whole canal of 16 miles could be completed for the sum authorized by law, 400,000 dollars; and 3d. That if the stockholders would punctually pay the sums subscribed by them, a toll for a part of the canal might be drawn in 1796, and the whole completed in 1797 or 1798.

Although this report was calculated to call forth the activity of the company, it had not that effect; the stockholders becoming gradually backward in paying their subscriptions, and of course the work began to languish. It was not, however, speedily abandoned by Mr. Weston; he continued his services, and reported in February 1796, 1st. That nearly six miles of the canal were navigable; 2d. That the most difficult parts of the route were overcome; and 3d. That it would be best to complete two miles more at the south-east end of the canal, from the three miles completed north-east of Philadelphia, to the falls of Schuylkill.

Nothing, however, could induce a great number of the subscribers to pay in the instalments, agreeably to their engagement, and thus the work ceased from the want of funds.

Under these circumstances, the stockholders of the Susquehanna and Schuylkill, and Schuylkill and Delaware companies, who had made good their engagements, petitioned the legislature to aid them. The legislature accordingly passed a law, authorizing the two companies to raise by way of lottery 400,000 dollars, two-thirds for the Susquehanna and Schuylkill, and one-third for the Delaware and Schuylkill canal. The first class of the lottery was drawn, the prizes duly paid, and 50,000 dollars realized by the companies; but, after the second class had been drawn, it was found that the whole of the prizes could not be paid. This result has never been satisfactorily accounted for, but I have been told that the misfortune originated in this way; as the tickets were sold, the proceeds were applied to carrying on the works, upon the assurance that the delinquent subscribers would meet their engagements in time to afford funds to pay the prizes; those subscribers, however, did not pay their instalments, and the failure to discharge the prizes was the consequence.

It appears, then, that the cause of the stoppage of both these important works were these; 1st. The novelty of the undertaking and consequent mismanagement at the outset; 2. The failure of the subscribers to fulfil their engagements. To afford some idea of the extent of the last mentioned evil, I state, that two of those, who had subscribed for the largest number of shares, not only evaded payment upon any of them, but appropriated 28,000 dollars of the money paid by others to their own use, and having subsequently failed, the whole was lost.

The total amount expended upon the Delaware and Schuylkill canal was 221 710 dollars and six cents. The sums expended in making the works at the summit-level between the Schuylkill and Susquehanna, and in purchasing ground for the canal, locks, towing path, &c. amounted to about 250,000 dollars."

As is seen in Mr. Raguet's report, these two companies were incorporated in 1811. The operations by the Schuylkill navigation company on the Schuylkill have been two years in progress, and are in rapid advance; the present amount of work done may be seen from inspection of the prefixed table. On that part of their enterprise, which is intended to carry a water communication from the Susquehanna to the Schuylkill river, through the Swatara and Tulpehocken creeks, the board of managers of the Union Canal Company, on the 20th of November 1821, made the following report:

"Immediately upon the organization of the board, in the month of May last, a committee was appointed on the important subject of an engineer. That committee entered with alacrity upon the duties assigned to them, and having communicated, by letter, with almost all parts of the United States, where canals had been undertaken, they collected a variety of information as to the talents and qualifications of different individuals, who had been, or were then, engaged in works of that description.

From the knowledge thus obtained, the board determined to select Loammi Baldwin, Esquire, of Boston, as the engineer, and a negociation was accordingly opened with him on the subject, through the agency of James Lloyd, Esquire, formerly of the Senate of the United States. Pending this negociation, Mr. Baldwin visited the line of the canal, as projected, near Lebanon, in company with a committee of the board, for the purpose of satisfying himself upon the practicability and general nature of the undertaking; and an agreement was finally made with him to enter the service of the company, on the thirteenth day of September last, that being the earliest period at which he could free himself from his private concerns and pre existing arrangements.

Having chosen Mr. Baldwin, upon the concurring testimony of gentlemen of the first character in different parts of the United States where he has been employed, the board feel an assurance, confirmed by the experience had during the short time that he has been engaged by them, that his science, skill, and diligence, have not been unduly commended, and that his selection is an event highly propitious to the interests of the undertaking.

The Board having had, previous to their appointment, but little personal knowledge of the country through which the canal is intended to be carried, the members have at different times arranged themselves into committees, who have, as occasion presented, visited it for the purpose of information. The first of these visits was made on the thirteenth day of June last, when measures were arranged to survey and level the western descent, from the summit, by the course of the Quitapahilla and Swatara, to the Susquehanna, the fall of which had not been before ascertained. This survey was accomplished throughout, under the personal superintendance of the President, and is believed to have been made with great accuracy.

The distance, following the margin of the streams, is thirty-four miles and eleven perches, and the fall from the water surface of the summit to the Susquehanna, at the mouth of the Swatara, as thus ascertained, appears to be 220 feet.

Which, added to the fall of the Tulpehocken, from the same line to the Schuylkill, as reported by Mr. Weston, . .	310
Gives a total of . . .	530

To be overcome by locks, according to the plan as formerly in part executed.

Should the summit, however, be lowered, a saving of lockage will be made at each of its ends, equal to the amount of the reduction.

The result of this survey also shows, that the surface of the Susquehanna, at the mouth of the Swatara, is 276 feet above the tide at Philadelphia.

Suggestions have been made as to the practicability of cutting through the middle ground which divides the waters flowing into the Quitapahilla from those flowing into the Tulpehocken, and by lowering the summit about forty feet, causing those streams to mingle at a common level, where the supply of water was deemed abundant, the same opportunity was improved, to make various examinations connected with that object. Levels and borings were taken, in order to ascertain the nature of the soil, and the probable quantity of excavation.

Similar examinations were made along and near the line of the old summit, where wells also were dug, for the purpose of discovering the difficulties to be encountered, should it be found expedient to continue upon that route, at a lower level.

The different services above mentioned having occupied the time of the president until some time in the month of August, he was then requested by the board to proceed to Massachusetts, in order to view the great dam and locks lately completed by Mr. Baldwin between Boston and Brooklyn, and the Middlesex canal; and to return through New-York, for the purpose of examining the works of the Erie and Champlain canals. From Boston, he was accompanied by Mr. Baldwin, and having gone to fort Edward on the latter, and to Rome on the former, they returned to Philadelphia on the twenty-seventh day of September. Much information was obtained in the course of this tour, the usefulness of which, the board have no doubt, will be apparent in the progress of the work.

The engineer commenced his labours at the middle ground on the fourth day of October, and from that time has been assiduously engaged in his duties there. On the nineteenth instant, he presented his report relative to the summit, which now awaits the decision of the board. Upon a perusal of this report, the board are of opinion, that every doubt as to the supply of water, and the entire practicability of the undertaking at the summit, the most material point, must vanish.

The board are sensible of the anxiety which is felt by the public, relative to the great state object entrusted to their care, and have been strenuous in their exertions to fulfil whatever might be reasonably expected from them. They are also aware, that an actual commencement to excavate some part of the line of the canal, would be generally considered a more satisfactory evidence of their diligence than any thing which it is now in their power to exhibit. They beg, however, to remark, that every work of this nature must depend, in a great measure, for its successful and economical accomplishment, upon the due adjustment of its plan, so as to guard all points of difficulty, and take advantage of all that are favourable. Until the engineer should have a full opportunity for examination, the board have felt it to be their duty, not to incur any considerable expenditure upon views, which might eventually prove defective or impracticable.

No time will now be lost in determining upon the plan; after which, contracts will be entered into, as soon as possible; and a small supply of tools and implements having been already provided, such progress will be made with the work as the season may permit. Much cannot, however, be accomplished, until the ensuing spring. In the interim, the details of the work will be thoroughly prepared by the engineer, and every arrangement will be made to prosecute it with the most vigorous industry.

The accounts of the treasurer, herewith submitted, will show the particulars of the sums received and paid by him, and the balance of $53,665 03, remaining in hand on the first instant.

A statement of the lottery fund is also annexed, exhibiting the amount of 72,245 dollars and 12 cents as having accumulated from that source, in aid of the funds of the company. Of that amount, 62,645 dollars and 12 cents were invested by the late board of managers in six per cent. stock of the United States, the par value of which is 59,389 dollars and 96 cents, and the balance remains in cash, the authority to invest under the charter having expired at the end of the year 1820.

A schedule is hereunto annexed, which exhibits the real property near Lebanon now held by the company, consisting of the water rights and the feeders, and the land occupied by the line of the canal for an extent of about eight miles, and some grounds purchased for brick yards. The water rights include all the main sources of the Tulpehocken and Quitapahilla creeks. The original cost of so much of this property as was paid for according to valuation by inquisition, was about 49,000 dollars, and of the residue, which was obtained by private contract, about 7,000 dollars. Almost the whole of this property may be considered as not only available, but essential for the purposes of the canal.

There appears also to be vested in the company a part of the ground occupied by the Delaware and Schuylkill canal, the cost of which is believed to have exceeded 4,000 dollars, but the precise amount has not been ascertained.

On the subject of future income from lotteries, the board feel great pleasure in being enabled to state, that they have made a contract with a gentleman of the first respectability upon terms far more advantageous to the company than those heretofore obtained; and they feel warranted in the opinion, that ample means to meet the interest upon the new stock will be raised from this source, without having recourse to the treasury of the commonwealth for the payment of any part of it.

As the question of compensation to the officers of the company will naturally arise at this time, the board deem it proper to remark, that, from the period of their organization, the attention of the president has been almost exclusively devoted to the affairs of the company. During a large portion of the time, he has been absent from his residence in its service, having encountered much fatigue, and devoted himself with industry and assiduity to its interests. A portion of the time of the secretary and treasurer has also been required daily, from the same period. Under these circumstances, it appears to the board but just, that the salaries which may be agreed upon should date their commencement as early as possible after those gentlemen were severally appointed.

Having thus placed before the stockholders the measures adopted in the performance of their duty, together with a general statement of their affairs, it may be proper to bring into view some of the advantages which will most probably result from the completion of this important work.

In the examination made by the president of the operations on the Middlesex canal, he ascertained that a horse, attended by a man and a boy, can convey about twenty-five tons twenty-five miles in one day; the expense of which would be as follows:

One man at one dollar per day, .	$1 00
One boy at 50 cents do. . .	50
One horse at one dollar do. . .	1 00
Use of the boat do. . .	1 50
Extra, ...	1 00
Per day,	$5 00
At the above rate of travelling, it would require three days to pass from the mouth of the Swatara to the mouth of the Tulpehocken . .	$15 00
Toll which may be demanded by the company, $1 40-100 per ton, on twenty-five tons,	35 00
	$50 00

Making two dollars per ton, or a fraction more than eighteen cents per barrel of flour, for seventy-five miles of distance.

Suppose, then, that the canal should be navigable 250 days in the year, and that there should be an average passage of only 15 boats per day, the above toll of $1 40-100 per ton would produce $131,250: thus leaving to the stockholders, after a full allowance for repairs and expenses, an income which would give an ample remuneration for the application of their capital, and to the public a mode of conveyance of about one-fifth the cost of the present land carriage.

While, however, these results may reasonably be looked for, it must be obvious, that by producing a more intimate connexion between the interior of the state and its commercial capital, they will tend to cement the good will which ought to exist between members of the same community; and that while efforts of the most extraordinary magnitude are making by our enterprising neighbours to engross the trade of the west, the completion of the Union canal, in connexion with the Schuylkill navigation, may be considered as the great link of a system of internal navigation, which, by affording a cheap and certain mode of transportation, will enable the state of Pennsylvania to retain the high standing which the extent and industry of her population, and her resources, so justly entitle her to.

In closing this report, it may not be irrelevant to remark, that the managers of the Schuylkill Navigation company, believing that a union of interest exists between the two companies, have determined, even at an increased expense, to extend their canal navigation below Reading, instead of keeping, as was originally intended, in the bed of the river: thus giving to the boats which may pass through the Union canal an increased facility in their approach to Philadelphia."

From information received at their office in Philadelphia, the Union Canal company commenced their operations on the summit level, on March 15th, 1822, with every favourable appearance of a successful issue.

We might indefinitely enlarge upon the subject of the great canal operations of the interior of Pennsylvania, but we trustsufficient has been given, to enable the reader to form a correct idea of the actual condition of those very important works. We now proceed to the discussion of another, and, perhaps, to its extent, the most necessary canal which could be formed in the United States, and the one most capable of execution, at the least comparative expense: that between the Delaware and Chesapeake bay. That this very obvious work should have remained to this date unfinished, must be considered as a public reproach. Prefatory to any remarks of our own, we present our readers with the two following documents, consisting of, a report of a committee of the senate of Maryland upon the subject of the Delaware and Chesapeake canal, and upon the internal improvement of that state, in respect to canals generally; the other, a report of a committee of the citizens of Philadelphia, and of the stockholders to the Delaware and Chesapeake canal. Taken together, they contain so much respecting the objects embraced, as to leave little to add which could interest the public; we therefore lay them before our readers, and shall close our review of the subjects with a few brief remarks.

The committee, to whom was referred so much of the governor's message as relates to internal improvement, beg leave to report:

That whatever difference of opinion may heretofore have existed, as to the expediency of internal improvements, the time appears now to have arrived, when every citizen of the state of Maryland is solicitous that all proper means should be adopted to bring into life and activity every internal improvement of which the state is susceptible. That, fully aware of this feeling, your committee would respectfully suggest some distinct objects of internal improvement, which they cannot but regard as of the very first importance to the welfare of the state—that is, The improvement of the navigation of the rivers Potomac and Susquehanna—the cross-cut canal (as it is usually called) to unite the bays of Chesapeake and Delaware; and the making of a turnpike road from Boonsborough to Hagerstown, with a view to join the great national road, lately completed by the United States, from Cumberland to Wheeling, in the state of Virginia.

With respect to the improvement of the navigation of the river Potomac, your committee are of opinion, that every reasonable aid should be afforded by the state to effect that desirable object; but when they find that the state of Maryland has already advanced one hundred and fifty thousand dollars for that purpose, without deriving the slightest benefit from it, they cannot but think that it is time to pause before advancing further sums of money, except so far as to complete the surveys already made, or undertaken, to procure correct estimates of the expenses of effecting the proposed object, and the extent to which the improvement of the navigation of that river is intended to be carried.

And here your committee would remark, that some doubts of the value of this improvement have been suggested to their minds by a perusal of the following extract from the report of the late Mr. Latrobe, dated March 16th, 1808, to Mr. Gallatin, then Secretary of the Treasury of the United States: "The trade of this canal, especially during the year 1807, has been so great, that there appears every prospect of its becoming a productive work, in those years in which there is a considerable and equal quantity of water in the river; *but on this circumstance it must always depend.* The information respecting it, which can be obtained from the company on the spot, renders it unnecessary for me to say more upon it."

Mr. Latrobe's opinion, upon a subject of this nature, being, in the estimation of your committee, entitled to the greatest respect, they conceive, that, before any farther advances should be made for the improvement of the navigation of the Potomac, the doubts suggested by this extract from his report, should be fully and accurately examined into, in order to enable the general assembly to form a more correct opinion upon the subject, than the information which they now possess will enable them to do. It appears, from a report of the Potomac company, that the total amount of tolls received by them, from the 1st day of August, 1799, to the 1st of August, 1817, was 162,379 dollars 55 cents, or $9,021 per annum, all of which amount, except the sum of $3,890 55 cents, was applied to the further improvement of the river. The value of property brought down the river, during the same period of time, is estimated at $7,002,370 62 cents, equal to $289,000 annually.

As it regards the improvement of the navigation of the river Susquehanna, your committee, viewing it as a subject of great and boundless importance to the state of Maryland, have given to it their fullest and most attentive consideration. The attention of the citizens of Maryland has recently been directed towards it, and all, convinced of the vast utility and benefit to be derived from it, seem anxiously solicitous that some legislative aid should be extended towards it. Under these circumstances, your committee cannot but recommend it as a subject worthy of the deepest reflection, and fraught with considerations of vital importance to the state of Maryland.

That particular district of country to which the benefits of the turnpike roads in Maryland are most immeately extended, lying between the Susquehanna on the one side, and the Potomac on the other, and extending north-westward from Baltimore to the north mountain, comprehending the Conococheague valley, has been accurately measured on a map of the country, and found to contain 5000 square miles. Those portions of the country bordering upon the various tributary streams of the Potomac, westward of the south mountain in Maryland, and the blue ridge in Virginia, have been also measured, and found to contain 10,000 square miles.

But when your committee direct their attention to that portion of the country through which the Susquehanna flows, they embrace within their view a field of greater and more enlarged dimensions. By an accurate measurement of those expanded regions situated upon the Susquehanna, and its numerous wide spreading branches, they have been found to contain about 20,000 square miles, exclusive of 10,000 square miles more of adjacent country, lying upon other waters in the states of Pennsylvania and New-York; for the produce of which country, should the navigation of the Susquehanna be improved to the extent contemplated, Baltimore must inevitably become the most convenient market.

From these estimates, it is abundantly evident that the trade of the Susquehanna, (flowing as it does through a country of vast extent, and inferior, in point of fertility, to no portion of the United States,) is a trade, involving in its nature a very extensive, permanent, and growing interest.

Were the navigation of the Potomac improved to the utmost possible extent, its trade must be considered but of minor importance, when compared with that of the Susquehanna; the Potomac flowing as it does through a country of comparatively small extent, and by no means celebrated for its richness and fertility. In addition to this it may be remarked, that, to however great an extent the productions of the soil may find their way into the Potomac; however extensive the demand for foreign commodities, at Georgetown and Washington, the state of Maryland can derive but little benefit from it. The advantages secured flow into a different channel: they go to fill other coffers—not those of the state of Maryland. But improve the navigation of the Susquehanna to the extent proposed, and you bring to the city of Baltimore a trade of incalculable extent and value, the benefits of which must be imparted to every section of the state, and which cannot fail richly to remunerate us for whatever aid may be extended to it.

The obstructions to the free navigation of the river Susquehanna, exist near tide water, that is to say, below Columbia. Above that town the difficulties are removed by Pennsylvania, and a boat navigation at present exists to near the New-York line. The distance from Columbia to Port Deposit is 35 miles, 20 miles of which may be considered as tolerably good navigation, either in ascending or descending.

From Turkey Hill to Nelson's Falls, near Muddy creek, a distance of 15 miles, the navigation is bad, and it is here that the principal obstructions exist, the removal of which are so anxiously desired.

Your committee have taken considerable pains to ascertain the value of the produce which has come down the Susquehanna for several years past; they have, however, only been able to procure an estimate of what has come down from last spring to December past; and they find it to be valued at $1,121,250. The number of rafts and boats that came down the river to Port Deposit, during the same time, was, 925 rafts of lumber, averaging 25,000 feet each, and 535 arks, loaded with flour, whiskey, pork, &c.

The Susquehanna canal, commencing at the Maryland and Pennsylvania line, and ending at the head of tide water, is now completed, and in good order for the passage of rafts. It appears to have a full supply of water at those seasons of the year when the river is not high, and insures a safe passage for all produce that may come down the river to the mouth of the canal.

It is certainly of great importance to the state of Maryland, that this canal should be kept in perfect condition, and that the proprietors be protected in all their just rights.

The committee have only to state in conclusion on this subject, that when the water of the Susquehanna is high, boats and rafts frequently pass to the head of the tide water without entering the canal.

The committee now come to the third object of internal improvement, to which they are desirous of directing the attention of the legislature; that is, the canal to unite the bays of Chesapeake and Delaware.

In the year 1799, the legislature of Maryland passed a law, which, in the year 1801, was followed by similar laws on the part of the legislatures of the states of Delaware and Pennsylvania, incorporating a company, with a capital stock of $400,000, for the purpose of opening a canal between the bays of Chesapeake and Delaware. In pursuance of these laws, subscriptions were received for nearly the whole amount of the two thousand shares, at $200 each. Surveys were made—engineers and workmen employed—a route selected for the canal through the isthmus which separates the two bays, and some material progress made in the execution of the work. But, unfortunately, after having gone thus far in the execution of this important object, and after having expended upwards of $100,000 in the purchase of water rights, and in the construction of a feeder and reservoir, the work was suspended, in the year 1803, in consequence of the non-payment of the subscriptions—and it appearing daily more evident, that the whole amount of the capital stock, even if subscribed for, and collected, was a sum totally inadequate to the completion of so extensive a work. At this period, also, the energy and spirit of the company began to subside, unaided, as it was, by further support and encouragement, or by that individual enterprise and activity which had enabled them, up to that period, to continue their operations.

By connecting the waters of the Chesapeake and Delaware, the contemplated canal will throw open an internal navigation of great extent, from the north-west part of the state of New-York, to the southern extremities of the state of Virginia.

The particular advantages which the state of Maryland would derive from this improvement, need scarcely be detailed by the committee. They will suggest themselves to the understanding of every reflecting man. In a national point of view, all will concur in the opinion of its importance, and, looking to an event which your committee is by no means anxious should soon occur, but, which, in the opinion of the committee, may reasonably be expected to take place at some distant period, it may be regarded as an object of peculiar interest, as productive of the means of national defence, affording, as it no doubt will, a facility of transportation of troops, ordnance, and military stores, from one part of the country to the other, the want of which was materially felt during our late war with Great Britain.

Beneficial as it certainly will be to the state of Maryland, the committee have thought it proper to direct the attention of the legislature towards it—but viewing it as an object of national concern, and not alone productive of local advantage, the committee would remark, that it is a subject to which the attention of the national legislature should be drawn.

The canal begins at Welch Point, on the Elk river, an arm of the Chesapeake, and is to terminate at a distance of twenty-two miles on Christiana river, a branch of the Delaware. At low water, the depth of water in Christiana river is 9 feet, and in Elk river 12 feet, within 100 feet from the shore. The tide rises 4 feet in both rivers. No expensive aqueducts or bridges are to be made, and the principal obstacles have been already overcome. The supply of water drawn from Elk river by a feeder which is now completed, six miles in length, and three and a half feet in depth, and which is itself a boat canal, united by a lock of ten feet high to the main canal, is calculated to fill daily one hundred and forty locks, a quantity sufficient, on an average, for the daily passage of 24 vessels. The canal is 26 feet wide at the bottom, and 50 feet at the water's edge. It is intended for vessels of from 40 to 70 tons, drawing 7½ feet. The banks, being intended for towing paths, are 20 feet wide, one of which may be converted into a turnpike road, being raised three feet above the level of the water, and will, by increasing the height of the lock gates one foot, admit a depth of nine feet water in the canal. The expense of digging one mile through rocky ground was $15,000, and that of digging the same distance through a level country, free from obstructions, $2300, which gives an average of $7650 per mile. The whole length of the canal is about 22 miles, and the whole cost is computed to be about $850,000. These estimates were made at a time when labour was comparatively high—it is presumed they would be much less at the present time.

This information of facts the committee have thought proper to furnish, in order to enable the legislature to form a correct opinion upon the subject.

The fourth and last object to which the committee have directed their attention, and to which they have thought it proper to direct the consideration of the legislature, is the making of a turnpike road from Boonsborough to Hagerstown, to join the great national road leading from the latter place to Wheeling, in the state of Virginia. Upon this subject the committee would remark, that this important object is now likely to be accomplished, in conformity with the law passed at the present session, and which, your committee trusts, will be carried into full and complete effect.

February 6th, 1822.

The committee appointed at a meeting of citizens, held at Judd's hotel, on the 4th day of September last, on the subject of the Chesapeake and Delaware Canal, report:

That they have collected all the laws passed by the states of Maryland, Delaware, and Pennsylvania, to incorporate the Chesapeake and Delaware Canal company; and the supplements thereto. In the law of the state of Delaware, there were discovered some provisions fixing the rates of toll, and reserving to that state a per centage on the annual profits, which, though they were rendered less objectionable, by a supplement passed on the 5th February, 1802, seemed still to interpose very serious obstacles. For the purpose of having them removed, memorials to the legislature of that state, then in session at Dover, were prepared by the committee, and two of their number were deputed to present them. On their arrival there, it was discovered that the obnoxious provisions had been repealed, and that the best disposition existed among the members to promote the important work to which these laws have relation.

Notwithstanding the primary object of the visit was found to have been already accomplished, your committee think that the trouble of the journey was more than compensated, by the opportunity it afforded of removing, by explanation, some prejudices and misconceptions, which existed in the minds of a few of the members of the legislature.

Your committee are not aware that there is any thing in the laws of the several states, in their present shape, which requires alteration or amendment; at least, antecedently to the recommencement of operations by the company.

Your committee have also individually, and by sub-committees, endeavoured to obtain information of the progress made by the company in executing the work; of the causes which produced its suspension; of the present condition of their affairs; and of its practicability and probable usefulness to the nation, and of the citizens immediately connected with it, as well as of the advantages it promises to the stockholders. For these purposes, and to collect and compare the information obtained, your committee have held meetings from week to week, since their appointment; and have derived, from a pamphlet recently published by Mr. Joshua Gilpin, much information of the most interesting kind; a part of which only is deemed necessary to lay before you in this report. The book itself is calculated to instruct and persuade all those who take an interest in the canal, both by the authenticity of its documents, and the manner in which they are explained. The opinions of the author, with regard to the route of the canal, will, of course, have their merits tested by future surveys; your committee, however, have learned nothing which could justify them in doubting the general correctness of Mr. Gilpin's statements.

In the course of their investigation, your committee have found cause to applaud the zeal and diligence of the former boards of managers. They speak, however, only in reference to their disinterested efforts in forwarding the great work committed to their charge. They will not presume to give an opinion upon the plans which those managers may have adopted in relation to the course of the canal, or the waters intended to be used as feeders: those topics, as already hinted, should be left, as your committee believe, to the decision of the present board of managers, in full confidence that they will be guided by the result of careful surveys, and an honest desire to benefit both the public and the stockholders.

The original subscriptions to this stock are as follows:

In Pennsylvania, chiefly in Philadelphia,	824	shares, by	429	sub's.
In Delaware,	712	do. do.	247	do.
In Maryland	256	do. do.	54	do.
	1792		730	

On these, Pennsylvania has paid	$73,400
Maryland about	18,300
Delaware,	11,300
Total,	$103,000
Leaving due upon the instalments called for:	
From Pennsylvania,	$9,100
From Maryland,	7,300
From Delaware,	59,900
Total,	$76,300
There have been received from the stockholders about	$103,000
And expended altogether,	122,000
Leaving the company in debt,	$19,000

The capital subscribed, (1792 shares, at $200,) .	$358,400
Of which there have been received, . . .	103,000
Leaving due from the stockholders, .	$255,400

Of these $255,400, it is presumed that 200,000 will be collected; and it is computed that an additional subscription of $600,000 would finish the work. These two items, added to the 103,000 dollars already expended, will make a grand total of about $900,000—the interest of

which, at 6 per cent. would be . .	$54,000
Annual repairs, and attendance on the locks, &c.	16,000
Total, ...	$70,000

Forty thousand tons of goods, it is supposed, are now annually transported across the peninsula, at a freight of 80,000 dollars. When the trade of the Susquehanna is added to the new traffic which will be created by the facility of a water conveyance, the increased tonnage must ensure to the stockholders large dividends.

The legislature of Pennsylvania directed the governor, by a law of the 25th March, 1813, to draw his warrant on the treasury for 75,000 dollars, (the par value of 375 shares,) whenever the United States shall have subscribed 750 shares, Maryland 250 shares, and Delaware 100 shares.

The board of managers have been re-organized by an election held at Wilmington on the 28th ult. and is to hold its future meetings in this city.

Upon the whole, your committee being confirmed in the belief that the canal is of the greatest consequence to the nation, and promises incalculable benefits to the inhabitants of the states and cities more immediately connected with it; perfectly satisfied too of its easy practicability, and at an expense bearing no proportion to the advantage it will yield to the public, and profit it will afford to the stockholders, beg leave earnestly to recommend it to the countenance and support of their fellow-citizens, so that the means may be promptly afforded to the board, of completing the work without delay. As it is a work in which the prosperity of Philadelphia is deeply involved, your committee believe they may make this appeal with confidence, and that it will be met with a liberality proportioned to its usefulness and magnitude, and consistently with the spirit for public improvement and patriotism, in which the committee venture to affirm our citizens never have been, and to hope they never will be, outstripped by those of any of our sister cities or states.

In conclusion, we invite you to contemplate the probable bearing which this work, associated with those already in progress, will have on the future fortunes of Philadelphia.

The Schuylkill and Lehigh open already the vast mines of coal which lie at their sources, and convey to your doors, at a cheap and expeditious rate, the rich products of the districts through which they flow; the waters of the Susquehanna, about to be connected by the means of the Union Canal with those of the Schuylkill, will furnish an easy and secure road to your market for that great agricultural territory; a descending navigation to the tide waters of the Chesapeake, with a convenient passage into the Delaware, will afford an opportunity for the boatmen to return home, not on foot, as at present, but by the Schuylkill and Tulpehocken rivers, on board their boats, with the proceeds of their sales, invested in your city, instead of other markets, as is now done. The construction of the Chesapeake and Delaware canal will complete this chain of inland navigation. It is for Philadelphia to furnish such means, as shall enable the managers to resume their labours and accomplish their end, and by consequence co-operate with the works of a similar kind now in hand, in securing to our city forever a rank, for wealth, population, commerce, manufactures, and general comfort, inferior to no other in the Union.

This report is signed by Samuel Breck, Mathew Carey, Thomas P. Cope, James C. Fisher, Paul Beck, jr. Stephen Girard, William Meredith, William Lehman, Simon Gratz, and Samuel Archer.

Mr. Thomas Gilpin has done for the Delaware and Chesapeake canal what Colonel Haines has performed for those of New York. Mr. Gilpin has published a luminous geographical and topographical *exposé* of the country, over which the former water communication must pass, pointed out the benefits to be derived from such a work, and suggested the most abundant and attainable sources of revenue to be applied to its execution. For the most enlarged detail we must refer our readers to Mr. Gilpin's work, and close our own observations by a few brief abstracts.

It appears from the evidence collected by Mr. Gilpin, that the project of uniting the two bays of Delaware and Chesapeake, originated as early as 1757 or 1760, nearly 70 years ago. Indeed so much has nature done towards the execution of a water connexion between those two inland seas, and so few obstacles to its completion present themselves, that an artificial completion of the work must suggest itself to any cultivated mind, to which the physiognomy of the intervening country would be made known. In the year 1769, the subject was brought before a committee of a company of merchants of Philadelphia, and the Philosophical Society. The latter body in that year appointed a committee also, but the members turned their attention exclusively to the pass between Bohemia and Appoquinimink.

In the various speculations on the subject of uniting Delaware and Chesapeake bays, several routes presented themselves, the principal of which were, that from the Bohemia or Sassafras river, to the Appoquinimink, that next below the latter, or from Chester river to Duck creek, and the third by Elk river to Christiana creek, or to the Delaware at New-Castle.

Each of those routes have been carefully and repeatedly surveyed, and the following geographical view and topographical extracts will, we trust, serve to give a clear idea of the country over which the canal is intended to be drawn.

The primitive ledge over which the Delaware flows at Trenton, and the Schuylkill near Philadelphia, continues to the south-west, parallel to the Delaware, to Wilmington. The latter town is situated on the point between the Brandywine and Christiana creeks, and on the verge of the primitive rock. Immediately below Wilmington the Brandywine and Christiana unite; the former rising within the primitive in Pennsylvania, draining the centre of Chester county, and the latter rising also partly on the primitive, and partly on the alluvial sea-sand border. The branch peculiarly called the Christiana has its source near the north-east angle of Maryland, flowing south-east, enters and flows north-east along the margin of the sea-sand border, and under the primitive ledge, receiving from the north White Clay creek and Red Clay creek, both issuing from Chester county in Pennsylvania, and, first uniting with each other, join the Christiana creek, between Newport and Christiana bridge. The tide from the Delaware flows up the Christiana to the bridge.

Elk river, similar to the Brandywine and Christiana, rises in Chester county, Pennsylvania, flows south about 20 miles to Elkton, where it meets the tides from Chesapeake bay. A short distance below Elkton, the Elk river turns south-east, and, passing Frenchtown, flows 15 miles to Turkey point, and is lost in the Chesapeake bay. A number of creeks rising on the alluvion flow westward into the Elk river, below the head of tide water; the principal of which are Bohemia and Back creeks.

Between the waters of the Christiana and Elk river, a ridge of land extends to the southward, down the peninsula, gradually lowering, but with many partial depressions, which render its altitude unequal. Below the primitive ledge the dividing ridge ceases to be rocky, except as containing rolled or loose masses, imbedded in clay and sand. The distances from the Delaware to Turkey point, as measured on Hill's and Gilpin's maps, are:

		Miles.
Wilmington		2
Newport	4	6
Mouth of White and Red Clay creeks .	2	8
Christiana bridge	3	11
Howell's upon dividing ridge . . .	8	19
Welch point, mouth of Back creek, .	8½	27½
Turkey point, mouth of Elk river .	9½	37

These distances are merely general, and may have, as relates to canals, very important fractional discrepancies, but they will serve with sufficient accuracy to mark the relative situation of places along the intended canal line.

Mr. Gilpin, who has exerted much energy of mind, and the experience of his whole life to the subject, appears to have demonstrated the propriety and necessity of approaching near the primitive rock ledge with the line of the projected canal. The following historical and statistical sketch, is founded principally upon information contained in that gentleman's work.

In January, 1770, a committee, composed mostly of gentlemen from Philadelphia, proceeded to Wilmington, and thence to Christiana bridge. Here they divided, and made extensive surveys on the peninsula between Red Lion and Back creeks, between Christiana creek and Elk river, and in the lower part of Chester and Lancaster counties. Mr. Thomas Gilpin, the father of Mr. Joshua Gilpin, was one of this acting committee, and in a great degree its prime mover. In the course of their investigations, the three routes we have already noticed were carefully examined, and their respective merits determined. The operations of the committee of 1770 enables the engineer of the present time to exhibit the revolutions effected by alluvion on the state of the respective water courses. Some of those changes are very striking, as will soon be shown.

From the survey of 1770, until 1799, no prominent steps were taken to carry this great enterprise into effect. During 1799, 1800, and 1801, the preliminary steps were taken, acts of incorporation procured, and, in May, 1803, the canal company was organized. The stockholders met in Wilmington, and elected the now chief justice of Pennsylvania, Mr. Tilghman, president; and Messrs. J. C. Fisher, George Fox, and Joshua Gilpin, for Pennsylvania; Mr. Tatnall, Mr. Johns, and Mr. Bayard, for Delaware; Mr. Gale, Mr. Chew, and Mr. Adlum, for Maryland, as directors.

A committee was appointed to execute new surveys, who met at Wilmington, July 4th, 1803. This committee was composed of the following members, Messrs. Tilghman, Gilpin, Tatnall, Johns, Gale, and Adlum. Mr. Latrobe, Mr. C. Howard, of Baltimore, and Mr. Thompson, of Pennsylvania, were appointed engineers.

The investigations of the committee and surveyors extended south to Bohemia and Appoquinimink creeks, and north to the primitive ledge and Christiana creek. "There is," says Mr. Gilpin, "also a remark with respect to the waters of the Chesapeake generally, proper to be introduced here, though it applies less to the Elk than to the other streams. These streams almost uniformly present to the eye fine sheets of water, with steep banks of gravel, sand, or other alluvial substances: they form also on the map deep indentations into the peninsula, apparently of the utmost value for canal communications, which has always led to the idea of those communications being much easier than is found to be the case in point of fact. In this respect, therefore, they are extremely illusory, as they are no more than estuaries, or inlets of the tide water of the Chesapeake, supported by no inland streams, but immediately degenerating at the head of the tide into rivulets of little use, either for natural or artificial navigation. Thus the head branches of Bohemia and Back creek are dammed up at the head of the tide for mills, and no one of them is able to supply more than one mill of feeble powers. From the loose nature of their shores also, they have all, since the settlement of the country, become so obstructed with shoals and sand banks, either at their mouth or within it, as to have very much lost their capacity for navigation, and to render it necessary that canals formed into them, instead of debouching at their upper extremities, should traverse their whole extent; which again is rendered nearly impracticable along their banks, by their loose structure and deep indentations; so that it is necessary for canal purposes to resort to the table land, or elevated ridges between the streams."*

It is, however, shown by Mr. Gilpin subsequently, that the navigable channel of Elk river is also slowly filling up, and that the point to which large vessels can reach, has considerably lowered within the last half century, and concludes his remarks on that stream by pointing out Welch Point, at the mouth of Back creek, as the debouch of the canal into the waters of Chesapeake bay.

The western shores of the Delaware Mr. Gilpin describes as "bodies of marsh extending several miles inland, obviously formed of the alluvion of its waters, driven on its bank by easterly winds. Through these the small streams, which, like those of Maryland, descend from the middle ground of the peninsula, wind in very narrow and devious courses, their channels being kept open by the action of the tide of the Delaware. Most of them, however, are small streams, whose navigation has become worse and worse, till they have been banked out. Appoquinimink itself is one of the best of them, and its navigation to the bridge is still kept open, though it admits vessels only of about 5 feet burden, and its course winds for 9 miles through marshes, while it is only 4 direct. It was said also, that in north-west winds, the bar at its mouth was sometimes nearly, if not quite bare. Such a creek, therefore, it was obvious, was unfit to form any part of the route of the canal.*

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* Gilpin's Memoir on the Chesapeake and Delaware Canal, page 8.

The reasons of abandoning all the lower routes are given in detail, and appear to be conclusive. The principal cause of preference of the upper route was, the facility and certainty of procuring feeders from the channels of Red Clay, White Clay, and Christiana creeks, and from Elk river, together with the superior cheapness of conveying the water of those feeders into the canal.

The committee directed the accurate survey of the upper waters for the supply of the canal; but while the engineers were preparing to go upon it, the country and waters, particularly those of White Clay creek, were very diligently explored again by Mr. Tatnal and Mr. Johns, in order to ascertain their elevation, probable quantity of water, and cost of purchasing them. The heights were ascertained, by taking those of the milldams and known falls between them, which gave them with tolerable accuracy, and showed them to be sufficient. The water they considered as at least equal to Elk river, and they found that the purchases might be made at a fair value. Soon after this, the engineers went upon them, and by the end of December completed their surveys, when it appeared by their report: That White Clay creek might be obtained, and brought to the canal, at an elevation of upwards of 80 feet, by a feeder 11 miles in length, which, though expensive and not eligible in the outset, offered a sure resource in the event of other means not being sufficient. The Christiana might be brought in the same manner as a resource, though with less quantity of water. But that the Elk was, beyond all doubt, the source of supply, proper at least to begin with; it could be brought very much on the course traced in 1770 from Elk forge, at an elevation of 84 feet, by a feeder of about 5½ miles, to the site of the canal upon the upper route. The quantity of water was estimated by Mr. Latrobe at 144 locks full per day—sufficient to pass 25 vessels each way. This feeder also offered all the important advantages that had ever been contemplated from it. A complete supply of stone and of lime for the canal; a very important revenue, in bringing down lime for the supply of the peninsula, which is wholly destitute of it; and the end of the feeder approaching within 38 miles of Lancaster, offered all those advantages, for conveying the produce of Chester and Lancaster counties, which had formerly been contemplated.

This survey, altogether, satisfactorily determined the most important points, upon which the whole structure of the canal depended; as it proved, that even if considerable allowances were made in the quantity of water, there was sufficient for as large a lockage as would take place upon it for a great number of years; that this might be largely increased by reservoirs in its neighbourhoood, and that there were ample resources for future times. It went, therefore, in a very great degree to determine not only the size of the canal, but its position also; since, wherever it was to be formed, it was from these sources, and these only, that it could be supplied.†

Re-surveys, and very extensive examinations, were again made in 1803, and 1804, and at a meeting of the board of directors, in April of the latter year, the committee of survey, and the two remaining engineers, Messrs. Latrobe and Thompson, (Mr. Howard having quit the business) laid the result of their proceedings before that board.

It had now become necessary, and ample had also been prepared to fix the route of the canal. One survey of Mr. Howard was of the utmost importance. By this document it appeared, that that gentleman had taken "a complete level of the elevation of the ridge between the Chesapeake and Delaware, beginning at its upper extremity, at Oliver Howell's, at the foot of Gray's hill, and extending down the ridge as far as the lowest branch of Bohemia, or the most southern pass; in order to determine what was the lowest level at which the ridge could be passed, in any direction between the approaching branches of the various streams. By this survey it was found, that there was no depression in the ridge, below 70 feet, until it came about a mile south of the Buck tavern, or about eight miles below (the southern termination of) the present feeder, and on the route from Back creek, or old Courthouse Point to Fort Penn. But this depression was to no more than 62 feet, or 12 feet below the summit level of the upper route; and in proceeding southward it soon rose again until it came below Middletown.‡

Combining every circumstance, the board of directors in April 1804 adopted the upper, or Christiana route.

May 2d, 1804, the work was commenced upon the feeder. "The plan of the canal designed a channel 50 feet wide on the water line and 8 feet deep."

The following extracts will close our remarks on the Chesapeake and Delaware canal; they are taken from various reports of the directors, and exhibit a history of the incipient operations of the company, and the causes of the suppression of the work. The first report was made June 4th, 1804. Much of the detail of the reports are omitted, as being already included in our own remarks, or in our extracts from Mr. Joshua Gilpin's treatise. In their first report the directors observe:

"In the plan of the work therefore upon the upper route, it will be seen, that the canal of these dimensions, from its entrance at Welch point, rises within one mile by eight locks to the height of 68 feet, on which level it continues for seven miles, when it rises 6 feet more, and continues for thirteen miles, to the first descending lock on the Delaware side. On this level the whole country has one uniform soil, without impediment, and is removed above those difficult and expensive works which abound on a lower level; in particular the passage of the roads admits of being provided for in a manner peculiar to a canal of this kind, by taking the advantages of hollows, and passing the roads of the country through archways underneath it, instead of the obstruction of drawbridges, a mode now universally practised wherever it can be done on the greater canals of Europe.

In designing these operations, and indeed the whole course of the surveys and plan of the canal, the board had continued reason to remark the illusory nature of the best plans which could be formed by superficial views, taken in walking or riding over the country; how often even the levels and surveys alone were but of partial use, and how absolutely requisite it was to have the knowledge and judgment of a practical engineer, to design, at every step the various species of work, so as to unite all their objects together.

From the period when the feeder was begun in 1804. two objects occupied the attention of the board, viz. the prosecution of the work, and providing funds for it. Accordingly, it was pursued with unremitting activity through the years 1804 and 1805, when a total failure of the funds compelled the board to discontinue it. During this period a great portion of the most difficult part of the feeder had been completed, besides the outfit and arrangement of the workmen; and a degree of experience in conducting the works was obtained, of the highest benefit, when they should come to be conducted on a larger scale.

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* Gilpin, p. 11.

† Ibid. p. 18.

‡ Ibid. p. 20.

If funds had been supplied in a manner commensurate with the operations of the board, there is no doubt that this great work would have been completed ere this, and the public would not now have to lament its failure, or to contemplate its revival. The causes of the failure of funds were simple and obvious; they did not arise either from want of confidence in the work, or in the conduct of it; neither of these were ever experienced by the board; but it arose from the great demand for money, and the numerous banks, insurance companies, and other institutions, which were commenced about that time, and offered such immediate remuneration for the sums invested in them, as overpowered the competition of one, which, however certain in the end, it required time to effect. The deficiencies of the stockholders in not paying up their instalments were at first partial, and the board hoped to counteract them by mild remonstrances, but, notwithstanding these, they became more and more extensive, and at last general. Suits were instituted in some instances to try the powers of the board in this respect, but they were resisted—it was vain to contend against the general deficiency, or to retain workmen and pursue operations, requiring a continual advance of money, upon the uncertain success of law-suits or further payments—the works therefore were discontinued; the most economical disposition made of their tools and other perishable property, to pay the workmen as far as they would go; and the works left in the best situation they would admit.

Thus circumstanced, there remained no resource but to apply to the legislatures of Pennsylvania, Delaware and Maryland, and to Congress, for aid. This has been done at every session since, in which there appeared to be any hope of success. Petitions of the most explanatory and forcible nature, accompanied by statements, calculations, maps, and every thing which could throw light upon the subject, have been constantly furnished—in particular, the legislature of Pennsylvania was attended, during one session, by a committee of the board, who laid before them that statement of facts and observations which is given herewith, in order more particularly to point out the benefit of this canal to the State of Pennsylvania, as a conveyance of its produce from the Susquehanna to its metropolis.

The issue of all these applications may be comprised in a very few words, viz. that except resolutions of the states of Pennsylvania and Maryland to subscribe to a certain number of shares when the United States and state of Delaware should do the same, which are thus far ineffectual, for want of their co-operation, nothing has been done; there has been no aid obtained whatever, and there now seems to be little prospect of it. For some years it is true, and particularly under the very active exertions of the late Mr. Bayard, there appeared to be strong grounds for belief that Congress would, in some way or other, patronize or support the work; since then however, and especially of late years, the business seems to have been more and more involved in uncertainty. Very formidable doubts have been raised on the score of unconstitutionality. This work has been made the parent or co-partner of other designs, that seem to have become more splendid, as the hope of assistance diminished, and which either might never be executed, or at least not in such a time or manner as might relieve the suffering interests of Philadelphia; and lastly, ideas which have been diffused in Congress, of the improper choice of the route, have given argument to those who were unfriendly or indifferent to the measure, and palsied the efforts of its friends. "Of what use," it has been said, "is it, to give assistance to a work, about which those who are concerned in it disagree among themselves?"

In this situation, without the command of a shilling, or any support whatever, the board of directors have had no part to act but to keep alive the constitutional existence of the company, and to wait for some moment, when the interests of the public might be manifested in its favour. Of late it has appeared to them, that while there was no efficient support to their measure, it only served to engender opposition and party opinion for them to move in the business, and this has been the real cause of their silence. So long as the works were in operation, and the board had any thing to communicate, they were ample in their communications, as their reports will show; these they had the gratification to perceive and know, at the time, were received with satisfaction by the public; but so long a period has occurred, during which they have had nothing to publish but their abortive attempts to obtain public aid, that what was satisfactorily made known before has been forgotten, and many crude ideas engendered, till at length a period seems to have arrived in which the zeal of the public has manifested itself in such a manner, as to revive the hope that they may receive sufficient support to proceed.

From the review of what has been done in this important work in the past, we naturally turn to the more useful consideration, of what is to be done in the future. In the outset of this, there seems to be no fact more probable, than that if ever this important work is to be revived and perfected, in the manner that the suffering interests of the city of Philadelphia require, it must be done by the enterprise and capital of its citizens, with the aid of those parts of the states of Delaware and Maryland which must always feel a deep interest in it, from being the theatre on which it is to be executed, and from the immediate benefit they must derive from it. The most important step in the prosecution of any measure for the purpose is, to proceed with unanimity—that unanimity which has been the main source of success, in the undertakings of the states around us—and to insure this, the most correct proceeding, is to examine with cool deliberation what has been done, and to ascertain how much easier and surer a foundation for success exists, in reviving and carrying that into effect, than by exhausting the time and attention of the public in desultory experiments or controversies.

It is to be observed in the outset, that there now exist acts of incorporation in all the three states which are immediately interested in this work—these were obtained with great difficulty, at a time when the enthusiasm in favour of the canal was at its height. In one state the act, after laying before the legislature for two sessions, was passed in the third by a casting vote. The hope of obtaining any other acts, should these be lost or infringed upon, is little; and indeed the differences of opinion which have arisen forbid it. Under this act there exists a company, a large number of stockholders, and a president and directors, who are the legal and constitutional organs for prosecuting this work; the respect due to this board, as a regular institution, is not only a common one, due to every body of the kind, but the support of it is a matter of interest to every stockholder and well wisher of the canal: what the conduct of that board has been, will be seen from the review that has been here given; and I trust it will appear, that, under the circumstances in which they have been placed, none could have acted with more correctness; when, as I have observed before, the names of the gentlemen, by whom the plan of this work was first fixed, are reviewed, I believe it will silence every idea of their acting either interestedly or prematurely—and the present board will, I trust, receive the same degree of confidence, when the depressing circumstances under which they have acted for some years past are known.

The zeal which has been lately manifested in the citizens of Philadelphia to revive this work is, it will be observed, the first favourable circumstance that has occurred since the operations on the canal began; and is such as the board of directors would have always hailed as the surest guarantee of their success, and always hoped they should at some period receive: such as it is, it cannot be too highly appreciated, nor the respectable gentlemen who compose the committee that has been formed on the subject: there can be no wish but to give them information, and to act with their assistance. It is certain, however, that, instead of wasting the time and patience of the public in the discussion of plans which may be offered, even by ingenious and well meaning men, but which the more they are indulged will divide the public opinion—if the work be resumed where it was left, a recommencement of active operations may be actually carried into effect, in the time that would be otherwise lost in deliberation. Indeed, such preparations might be made this winter, as would admit it the moment the season opens in the spring.

It is obvious, that if the present board had the means of recommencing the work, or whenever they should possess it, one of their first objects would be, a revisal of their former proceedings, in which every attention would be given to the general sentiments of the stockholders, and to every reasonable plan which has been elicited; while this would be done under all the advantages arising from former information, and with that just discernment between plans founded on local views or ingenious theory, and those of real practicability and public benefit; a discernment for the exercise of which it is, that the directors of this or any work are chosen, and which constitutes the most essential part of their duty; it is obvious that new engineers must be appointed, since the death of Mr. Latrobe has of course put an end to the idea of employing him, even had it been contemplated. With new engineers a decent conformity to their opinions would follow of course—of the necessity of the feeder there can be no doubt, and that might be recommenced and carried on, while every other point was investigated; particularly the line of the canal and the debouches, especially the eastern one, upon which the chief difference of opinion seems to rest. On this head I have already mentioned, that no party exists in the present board: their object was to get the more important part of the work done, and this question would have been settled by them without disturbing the public mind. Since the suspension of the work, the erection of a bridge at Wilmington has thrown impediments in the navigation of that creek, or at least all the disadvantages of a draw-bridge, and the works erected on the Pea-Patch it is presumed will defend the entrance of the river; and though it does not follow from hence, that it would be more proper to place the debouche of the canal where it might become the scene of military operations, nor do away the natural disadvantages of the shore, or so low a situation on the Delaware; yet these united circumstances now give a considerable preponderance to the situations on the Delaware generally, and especially that at New-Castle, where there is decided bold water, without the impediments existing below, and the dangers of exposure may be overcome by a mole or embankment, at less expense than in any other situation without the Christiana. Here also the peaceable traffic of the canal is equally defended by the works of the Pea-Patch below, and rendered more secure by its distance from the actual scene of operation.

Whether however the debouche be in the Christiana, at New-Castle, or at any point below it, is a matter of less moment to the citizens of Philadelphia, than that it be begun and executed in a useful and economical manner. While the work remains at rest, the public will continue to be agitated by local interests and plans, all sanguine in their objects, and all obtaining some advocates, as the board of directors experienced before; while the business at last must be settled by the judgment and authority of some delegation, and never more properly than by the legal organ of the stockholders, uniting the knowledge of what has already been done with a disposition to pursue anew every necessary investigation, and determine it with unbiassed integrity.

That the stockholders and public may have the best information to proceed upon, I shall now give a statistical explanation of the state of the company; premising, that this is principally drawn from a letter which I wrote, in 1808, to Mr. Gallatin, formed, at that time, from the papers of the company, and a comparison of opinions with Mr. Latrobe; since which, I have reviewed it so far, that I believe it is as accurate as the nature of the subject admits.

First—The state of the company's accounts is as follows:

There has been received from the stockholders about	$103,000
And expended altogether . . .	122,000
Leaving the company in debt . .	19,000

This debt, which may be taken at the round sum of 20,000 dollars, includes all that the company owes, except for lands and water-rights not yet taken into possession, which of course must be considered as a new expenditure, and enter into the estimate of what the canal will now cost. It is to be observed, however, that at least $20,000 has already been paid for those lands and water-rights, which may in some degree be balanced against what they owe.

The expenditure includes all the surveys; the *materiel* or outfit for the work; the whole of the contingent expenses, and the works on the feeder.

Second—The capital of the company is as follows:

The amount of the original subscription was 1792 shares, at $200 a share	$358,400
Of which there has been received .	103,000
Leaving	255,400

Yet due from the stockholders, subject no doubt to some allowances for bankruptcies, intestate estates, &c. though this allowance must be contingent upon the spirit with which the work is revived, and the consequent demand for shares, which will of course occasion a greater or less desire to pay the arrearages. It is probable however that, under all circumstances, the capital of the company may be rated at	$200,000

Third—The estimate of the future expenditure may, I believe, be taken with as much correctness as it is possible to attain, as follows:

To pay the debts of the company .	$20,000
To complete the purchase of the water-rights on Elk river, and land on the feeder, ...	40,000
To complete the whole work on the feeder	30,000
To purchase the land on the course of the main canal, 4,200 acres at $12, say .	50,000
To complete the whole extent of the canal fit for operation, except the locks, $20,000 per mile, on the longest route, say 22 miles	440,000
To complete 18 locks, averaged at $10,000 each	180,000
For contingent expenses . . .	10,000
	$770,000

Should the route go into the Delaware, some allowance must be made for an artificial harbour, though the calculation of $20,000 per mile, on 20 miles of the upper route at least, is so liberal, considering the nature of the ground, that it will probably admit of paying for a harbour, especially at New-Castle, where it will cost less than at any other place. It may, however, for the sake of round numbers, be proper to estimate the total future expenses at $800,000

From which if we deduct the present capital	200,000
There will remain of new capital to be provided	600,000

Fourth—The revenue and probable reimbursement of capital or interest is a subject of course of no small importance: on this, as information was required by Mr. Gallatin in 1808, I took every pains to investigate the subject, and shall give the result. In the outset, however, it may be necessary to state the net revenue that will be wanted. If to the $103,000 already expended there be added $800,000, the work will cost, say $900,000, the interest of which will be $54,000

Annual repairs	10,000
Attendance on the locks, clerks, &c. .	6,000
	$70,000

The tolls on a route of this distance would, in England, average 2½*d.* sterling per ton per mile, or 55*d.* for 22 miles; but taking it at $1 per ton, it would require the passage per annum of 70,000 tons, to pay the above revenue; or 240 tons, or 5 vessels of 50 tons each per day, for 300 days in the year.

The probability of obtaining this depends upon calculations of two different kinds—1. The existing traffic—2. The new traffic which may be expected. The first of these seems to afford some probable data, and accordingly I endeavoured to obtain the best information I could of the produce carried across at the different portages, and the cost of it; by which I found it, as near as a subject naturally so vague in itself admits, as follows:

The amount of goods . .	Tons 400,000
The carriage of it	$80,000

It must be obvious, however, that the existing land carriage, by bad roads, can give but a very partial view of the revenue to be derived through an unlimited intercourse by water, and that the great expectation of revenue must be founded upon the new traffic to be created, of which, though no idea approaching to accuracy can be formed, very reasonable conjectures, that it will be very great, may be made from the following circumstances. It is probable that the craft occupied in the two bays of Chesapeake and Delaware amount at least to 1200 vessels of 40,000 tons, out of which we may presume that many more than 7 vessels will pass per day. Indeed, if 50 vessels of 50 tons should be engaged in the trade, and each pass 30 times through the canal in the course of a year, they would carry more than the requisite tonnage, say 75,000 tons.

The probability of this employment may be conjectured from the following considerations:

First—The great interchange of merchandise between Philadelphia and Baltimore, and the other towns on the Chesapeake.

Second—The attraction of all those heavy articles, the productions of either bay, to its head, and thence across the canal. And here we may observe, that it is these upon which the revenues of all canals in Europe are founded, more than upon the passage of merchandise, as their great quantity and great bulk or weight, gives a vast revenue. If coals alone be attracted from Virginia to the manufactures on Brandywine and Christiana, it will give a new feature to them, by introducing those of iron, and afford a large revenue—if to Philadelphia, so as to be sold cheaper than foreign coal, it would be still greater. Independent of this, on the one hand, are the lime of Pennsylvania through the feeder, to all parts of the peninsula below, the produce of the Susquehanna to be brought round, and the wheat, Indian corn, tobacco, cotton, &c. of the southern states; and on the other, all those articles with which Philadelphia supplies the southern states; without taking into account what may be expected from an extension of intercourse to New-York at one end, and the southern states at the other, by canals, of which the present one will probably be the parent.

In contemplating the resources of the board, we must mention the very ample powers to raise money, to an unlimited extent, as there is no particular sum to which the capital is circumscribed. Under these powers, the board felt great confidence in their original proceedings, for though the subscription was not sufficient for the whole work, it appeared amply so to complete the western end and feeder, upon which there would have been an immediate traffic; as the produce of the Chesapeake would then have been brought to within a few miles of Christiana bridge, and other landings on that creek, which would have given the company an active property whereon to raise loans, or would have so far inspirited the stockholders, that new subscriptions could be obtained, or the powers of the company to raise money resorted to. But the defection began so early, as to deprive the board of every resource, it being obviously useless to ask for loans without an estate to mortgage, or new subscriptions when the old were unpaid. There was then no hope but in public aid, the failure of which left the board without the least appearance of support, till the present moment.

In order to judge of the interest taken in the present work, and where the subscribers to it exist, it is worth while to take a view of the original subscriptions, which are as follows:

		Shares.	Subscribers.
In Penn. chiefly Philadelphia,		824	by 429
In Delaware,	Wilmington,	351	166
	New-Castle,	126	14
	Cantwell's Bridge,	125	35
	Pencader,	24	10
	Port Penn,	35	12
	Middletown,	30	4
	Duck Creek,	11	2
	Concord,	10	4
		—712	
In Maryland,	Elkton,	69	11
	Head of Sassafras,	85	17
	Chestertown,	45	19
	Easton,	57	7
		—256	
		1792	730

It will thus be seen, that less than one half of the subscriptions are in Philadelphia, and that Delaware has subscribed nearly as much as Pennsylvania. But in the payments the case stands differently, for of the sum received,

Pennsylvania has paid about	$73,400
Maryland about	18,300
Delaware about	11,300

So that of the deficiencies of the calls heretofore, there is due—

From Pennsylvania	$9,100
From Maryland	7,300
From Delaware	59,900
Making a deficiency of	$76,300

As this deficiency took place after the decision of the route and commencement of the canal, of course it had no effect upon them, although it must go now to abate the claims, which the deficient stockholders might otherwise have for their interest. It has been inquired of the board, whether the deficient shares have been declared to be forfeited, a measure which sound policy has heretofore rejected—in the fallen fortunes of the company, the deficient stockholders would willingly have received this as a relief from future demands, but amid their limited resources the board did not choose to deprive themselves of the hope of receiving the arrearages in one way or other, besides which it was dubious, if a general forfeiture was declared, whether a sufficient attendance of the general meetings could have been obtained, to keep up the board. What, therefore, would now be proper, if new subscriptions are obtained, would heretofore have been useless at least.

It would be for the board, if convened, to adopt the measures proper to be taken for the re-organization of the work. But as the public are alive to the subject, it may be satisfactory to point out a plan, on which it may be done, with great simplicity. The debts of the company are, as it will be seen, of no great amount; the importance of the work, and the probability of its paying an interest to the subscribers, great—if therefore new subscriptions could be obtained to the amount of $500,000 or $600,000, it would require 3000 shares, the instalments on which first required should be $100 per share, or the same that has already been required of the old stockholders, who should be called upon at the same time to pay up their subscriptions, or forfeit their shares, and thus the old and new subscribers would be consolidated on the same footing. If these subscriptions are obtained, there seems to be no reasonable cause of delay in recommencing and pushing on the works in the ensuing year. Those on the feeder are in a state to be immediately resumed; the substantial part of them is little injured, and a moderate expense will reinstate the whole. Besides which they will afford, as they have done heretofore, an opportunity for organizing the workmen and materials upon a small scale, preparatory to their being engaged on a greater one. If indeed the feeder was not essential to the main canal, in every position in which it could be contemplated, it would be a work of incalculable advantage itself, for drawing the produce of Pennsylvania to Christiana bridge, or other landings on that creek, and the distance to execute it for this purpose would be but a few miles.

I have already spoken of the probable revenue of the canal—but as this is a matter of primary importance to the subscribers, it may not be improper to enlarge upon it. I have mentioned that 5 vessels, or 250 tons per day, would probably pay the full interest and expenses, at a rate of toll under what is admitted by the acts, and which is altogether a very reasonable one in itself. It is almost unnecessary to add, that 10 vessels or 500 tons would of course double the revenue to 12 per cent. and if any thing near the number of vessels which can pass through in a day, actually do so, the revenue will, as it will be seen, be enormous. There is, however, another object, which, though of inferior importance, is not to be lost sight of. The mode of forming this canal, that is by its width, and by passing the roads under it, will admit the passage of steam-boats, a thing which is impracticable on almost every canal in Europe, owing at once to the necessary height of the chimneys in those boats, and the obstruction of bridges and tunnels on the canals, as well as the wear and tear of the banks where they are not very wide. These circumstances are so important, that Mr. Fulton assured me, in 1809, they were the reasons which prevented him from attempting to introduce his steam-boats on the canals of England. There is another circumstance from which revenue may be derived, viz. a turnpike road on the bank of the canal. This will be in a great degree essential to continue the traffic, at those times in which the canal is obstructed by ice, but it will be a most convenient and lucrative accommodation to the public at all times, for it is to be observed, that the bank of the canal is perfectly level throughout the whole extent, except just at the declivities of the locks—that it is at all times completely drained, and the carriage of materials by the canal itself will admit such a choice of them, as to make it of the most perfect construction. Upon most of the canals of Europe, their winding course and their interference with established turnpikes have limited this use; most of the canals, from the expense of land, and other motives of economy, have limited the road on their banks to a mere towing-path on one side, but the modern ones have extended them to each side. Here it is obvious, that one of these may be made a perfectly fine road, of 20 to 30 feet wide, without interfering with the purposes of the canal. The acts of the company do not, it is true, at present contemplate a turnpike, and there is now one from New-Castle to French-town, but the superb convenience of one of about 20 miles from New-Castle to Welch point, on the banks of the canal, would undoubtedly render it an easy matter of compromise with the present company, or obtain it from the public."*

In order to form a just outline of the work, and to fix a plan of proceeding for the engineers, under that superintendance which was enjoined on the board by the trust reposed in them, a committee of their body was appointed, who, with the engineers, proceeded to a general examination of the sources of supply, the situations on each bay, the respective passes supposed to be practicable, and of the nature of the country itself. From this investigation much important information was obtained, and a system of proceeding established for the more minute operations of the engineers. It also enabled the board to direct their attention to every point from whence utility and satisfaction could result to the public, to curtail the expense and time which would have been consumed in desultory and useless experiments, and so far to accelerate the business of the surveys, (sufficiently tedious even when confined to the most necessary objects) as to commence the execution of the work with the promptness and economy due to the expectations of the public.

In the course of this survey, and of the inquiries which attend it, many important general principles were established, to the satisfaction of the board as well as of the engineers. Among the first of them, was that of the general nature or kind of the canal itself. Upon this subject they were aware, that several different plans had been offered to the public, before and at the time of their appointment, to which they thought it their duty to pay a just attention; and to carry with them the ideas which had been suggested, in order to apply them to the country and situations which they explored. One of the most prominent of these plans was that of effecting the canal by a deep cut or channel on the level of the tide from one bay to the other, so as to connect the two waters upon one level. As this had gained considerable public attention, they thought proper, not only toi nvestigate its general principles, but to apply them to the positions which had been pointed out as most proper to admit of them. In examining the general principle, it appeared to them no other, than the revival of those ideas of artificial navigation which had existed previous to the invention of locks, and the execution of which had been found to present so many difficulties as to baffle a variety of attempts both in the ancient and modern world. In applying the principle to those places which were most favorable from the near approach of the respective tides, such a work appeared at once, if not wholly impracticable, at least beyond the reach of the funds of the present company, or of any which seemed likely to be formed for the purpose: to say nothing of the nature of such a canal when formed, of the operation of the two opposite tides, or of the doubts how far these operations might ever be subjected to the regulations of art. From the investigation of the subject therefore it appeared obviously to result, that no alternative remained to the board, but to adopt that kind of canal which should pass over the peninsula at a practical level with a lockage at each end, in the usual manner of those navigations which have been carried into such complete effect in Europe and in America, reserving the adoption of a larger or smaller canal to the time when a minuter investigation of the sources of supply should furnish the grounds on which to form a decision.

In exploring the various waters of the peninsula which seemed likely to afford a supply for the canal, it became at once obvious that this could be obtained from no other sources than from the waters of White-clay, Christiana, or Elk creeks; as all the streams below these were found to take their rise far below the level necessary for the canal, and also to be so scanty in their nature, as to afford no hope of supply. From hence the result was obvious, that the more southward the position of the canal, the greater would be the distance for furnishing it with water.

It also appeared that the navigation of nearly all the rivers and creeks on each bay was subject to difficulties for a considerable extent below their respective heads of tide, that positions for the mouths of the canal, on either bay, became more distant from each other as the line of the canal was carried to the southward, as well as more exposed to rougher navigation, especially below the line from Back creek to Port Penn; that the highest navigable position on the waters of Chesapeake, approaching nearest to those on the Delaware, was at French town on Elk river, opposite to Hamburg; Red Hook; New Castle and Christiana creek on the Delaware; the board, therefore, leaving the investigation of any route below that from Back creek to Port Penn as affording no hope of utility, adopted, from their preliminary survey, a plan for obtaining the accurate and detailed surveys of their engineers on all the proposed routes northward of that line.

In order to carry this plan into effect, and to leave no necessary point of examination incomplete, a committee of survey was formed to assist the engineers, by frequently accompanying them: and the board itself also held frequent meetings in order that the progress of the work might be known to them, and every measure taken which could conduce to its speedy and successful termination.

The operations pointed out to the engineers were as follow:

1st. To survey and ascertain the lower route from Port Penn on the Delaware to Back creek, with an extension of the line to old Court-House point on Elk river.

2d. To survey and ascertain the routes from French town to New-Castle, Christiana creek, Red Hook, and other positions on the Delaware.

3d. To survey and ascertain the elevation and probable quantity of water of White-clay creek, Christiana, and Elk respectively, and the course by which feeders and a reservoir might be formed to conduct these waters to the canal.

4th. To survey, sound, and estimate by actual measurement, the courses and depths of Christiana creek, of Elk river, and Back creek, and their respective channels, and also of the river Delaware at New-Castle, and opposite to Red Hook and its vicinity.

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* Gilpin, p. 33–47.

These operations, with several of a less important nature, which were from time to time thought necessary for the general investigation of the subject, were pursued with unremitting industry through the late summer. But the season being considerably advanced before the appointment of the board, it was found impossible to complete them before the winter put a close to all operations of the field, and its length and rigour prevented their recommencement till unusually late in the present spring. However reluctant therefore the board have been to delay the important measures of a decision on the route, of the commencement of the work, and of giving the result of their labours to the public eye, they have been compelled to it by circumstances beyond their control, and by their desire to effect their surveys in such a manner as should render them, not a vague, but an accurate guide to themselves and their successors: and they trust that their constituents will feel with themselves, that this delay is in a great measure compensated by the accurate and copious information which it has produced.

Without entering into the detail of these operations, which would be too tedious for the present purpose, it will be sufficient to mention their general result and the measures which have been founded upon them.

I. By the survey of the waters of Elk, Christiana, and White-clay creeks, and of the course of the feeder and reservoir, it was ascertained, that the supply to be derived from Christiana creek was at all times small, and in summer very scanty indeed; but that a copious supply could be obtained from White-clay creek and Elk river. Either of these streams were, as far as could be ascertained, sufficient for an extensive navigation upon the canal, with the advantage of adding the other whenever an increase of business should require it.

In tracing the line for the feeders from their respective streams at a sufficient elevation, to reservoirs in the vicinity of the canal, it was found that both could be conducted over practicable ground, but that the waters of Elk could be brought from the upper forge on that river at the elevation of 84 feet, by a route considerably shorter and less expensive than those of White-clay creek.

By the survey of the feeders several important general principles were also established.

1. That as the supply for the canal on any of the proposed routes must be drawn from White-clay or Elk creek, and along the same course from the reservoir, wherever might be the line of the canal, both the feeders and reservoir might be begun without delay.

2. As it was ascertained that a copious supply of water might be obtained, the size of the canal was established: the only doubt being removed, whether it ought to be so ample in its construction as to convey those vessels which were usually employed in the navigation of the two bays, or be made a mere barge navigation of moderate dimensions, to which it must have been confined had the source of supply been smaller.

3. That as a canal so ample in its construction could be formed, it became of the utmost importance to place the termination or embouchure on each bay in such situations as should afford a bold and open access, beyond the hazard of delay arising from shallow water, exposure to winds, or any of those obstructions which might lessen its utility, by impeding the most free and uninterrupted approach to it.

II. By the survey of the lower route, from Port Penn to old Court-house point and Back creek, and of the creek itself as connected with it, it was ascertained,

1. That from Port Penn to the head of Back creek the ground was highly practicable, but that from thence no eligible route could be obtained either to old Court-house point, or to Back creek, at such a level as could be supplied by any known feeder, or in any other manner than by a steam engine, or other artificial work. It appeared particularly from the survey of Back creek, that its mouth was so much obstructed, and its channel so narrow, as to render the creek itself in no degree proper for forming any part of the proposed navigation.

2. The situation of Port Penn also appeared by no means more favourable than those higher up the Delaware.

III. By the survey of the route from French town to the waters of Delaware, the general practicability of that route was established with such certainty, as to confirm the most sanguine hopes that had been entertained of the probability, and indeed the ease of forming a canal from the two bays adequate to the most important purposes. Indeed, in considering the survey of this route, it seems rather to present a choice of places, all practicable in their kind, than to oppose any material obstacles whatsoever.

In the deliberations on this route, the first important feature was that of the mouth or position on Elk river. After a survey of the port of French town it seemed to result, that although the navigation of Elk river, to and from the landing, or its vicinity, was at present highly practicable, yet, from the narrowness of the channel, and the existence of a shoal below French town, the navigation of the river, especially during the prevalence of south-westerly winds, was liable to delay, and not of that unquestionably bold nature, which the board were desirous to procure. Added to this, it was to be feared, that from the loose soil of the shores of the river, the slowness of its tide, and its being deprived of much of its head water by the operation of the canal, any disadvantage under which it now laboured might justly be supposed to increase, and perhaps others accumulate in the progression of years, to which it may be confidently hoped the utility of the present work will extend.—The ground also for some distance, although practicable for the canal, was found to be of a nature which would render it difficult and expensive. For these united reasons, the board entered into more minute surveys and soundings of the shores and channels of Elk river, in order to find a more advantageous position. None however offered nearer than Welch point, at the mouth of Back creek, where there is a bold and open point, projecting at once into a depth of water sufficient for vessels of almost any size, at any time of tide, or with any wind.

In order to verify the circumstances, which appeared so highly in favour of adopting Welch point as the mouth of the canal, the engineer was directed to make an accurate survey of it and of the route from thence towards New-Castle and Christiana creek. The result of this survey was, that the Point itself proved to be in the highest degree favourable to the constant approach of vessels of almost every description at all times, with a sufficient harbour, and situations proper for erecting the necessary locks and basin at the mouth of the canal, without extraordinary expense. In tracing the route of the canal from thence northward, until it joins that from French town, the ground over which it runs appears not only highly eligible in itself, but so far superior to the route from French town, that although the length of the canal is extended three and a half miles, a considerable part of the extra expense will be saved by the superiori- of the ground, and the difference, which it is supposed will not exceed 18,000 dollars, appears fully compensated by attaining a position on the Elk, which will in all probability secure for ever to the canal the desirable object of a bold and unembarrassed approach.

From either French town or Welch point, the canal, rising by a succession of 9 locks to the elevation of 74 feet above the tide, attains the summit level, at which it is conducted across the peninsula. At the distance of five and an half miles from French town, and nine from Welch point, the two routes unite, and continue on the same level across to the vicinity of the Bear tavern. Of this part of the route it is only necessary to remark, that the general direction of the canal is confined by nature to the course adopted, it being prevented from any material deviation to the northward, or southward, either by grounds which are too high, or by streams, ravines, or other formidable difficulties: and though the country possesses some irregularity in its general levels, it is in the main highly favourable to the purpose.

The canal, thus conducted to the vicinity of the Bear tavern, arrives at a point from which the route becomes different, according as it enters the Delaware either at Red Hook, Hamburg, New-Castle, or into Christiana creek.

From the survey of the country from the Bear to Hamburg and Red Hook it appeared, that though both these lines were practicable, that to Red Hook was far the most eligible, both as to distance and the nature of the ground.

It became however necessary to establish one general principle respecting these positions, by which they both appeared ineligible. For, by surveying and sounding the river Delaware opposite to them it was found, that the whole of the cove or bay extending from New-Castle almost to Reeden point was at once so shallow, to a considerable distance from the shore, and so subject to the danger and changes occasioned by the violence of winds and tides as to be in every part an improper position for the entrance of the canal.

The route from the Bear to New-Castle, which was the next in distance, was found to extend over very favourable ground until within 2 miles of the town, where it appeared that an embankment of considerable extent and expense would be wanted over Mill-creek, and the marsh on its sides.

In surveying the port of New-Castle as a position for the mouth of the canal, its bold and accessible situation was unquestionable, but it appeared to be more subject to exposure than was to be wished, and, although improved by the piers lately erected there, it was to be feared that the nature of the port was better adapted to the security and navigation of large vessels, than to the shelter and constant communication of those of a moderate and small kind; which it must be supposed will be chiefly employed in the traffic on the canal.

The route from the Bear to a position on Christiana creek, near Mendenhall's ferry, appeared in extent near one mile longer than the shortest of two proposed routes from the Bear to New-Castle, and the ground over which it extends was subject to some obstacles and irregularities of surface, especially as it approached Christiana creek. None of these however were either impracticable or formidable, and the position for the termination of the canal on the creek seemed at once to accomplish the object of a bold navigation, accessible at all times, and from the rapid tide and quantity of water likely forever to remain so, and that of a safe, commodious and extensive harbour, furnished by the Christiana itself, particularly suited to those vessels which would most probably navigate the canal, and sufficiently accessible to others.

In deliberating upon the two routes to New-Castle and Christiana, which in point of eligibility so nearly approached each other, the Board thought it perfectly within the general object of this and similar undertakings, to consider how far the interests of the Stockholders might be promoted by adopting such a position for the canal, as would probably most increase its traffic, and accommodate the greatest proportion of the interests of the Stockholders, under circumstances subservient to the greater interests of the public. While, therefore, the position on Christiana creek appeared perfectly accessible to the navigation of Delaware, and to establish as completely the intercourse from bay to bay, the Board could not but entertain an opinion that the important trade of the town of Wilmington, and the manufactures which were extensively conducted on Brandywine, White-clay creek, and other waters of Christiana, claimed an attention to their interests, which would in all probability be richly repaid by their increase, and, with them, the product of the canal.

In the prosecution of these surveys, a variety of collateral objects were necessarily pursued in subservience to, and as a confirmation of the general result of the work. Among these was a line of level along the ridge of the peninsula for some distance southward. But as the detail of these and many other operations are less the province of the Board than of the engineer, by whose talents and scientific knowledge they were accomplished, they do not enter into the present report.

Upon the close of the surveys, which, as has been heretofore observed, were protracted by the unavoidable circumstance of an inclement season, and an anxious desire to leave no necessary information unattained, the Board finally came to the resolution of fixing the route of the canal from Welch point on Elk river to Christiana creek, near Mendenhall's landing.

Of this resolution, which the Board are sensible had been for some time demanded by the public anxiety, and on which they are equally sensible that the opinions of many will be divided, they have only this remark to offer; that being the result of an indefatigable attention to the subject in all its bearings, of a research so extended as to leave no point of information unaccomplished, and of an unremitting deference and moderation among the members of the Board itself, they have no hope that any decision on a subject of such importance could ever be obtained under more favourable circumstances; and they trust that it will give satisfaction to every candid and liberal mind.

During the progress of the surveys necessary for fixing the general route of the canal, upon its being ascertained that the waters of Elk and White-clay creek must be resorted to for supplying it, wherever its position might be, and that the most economical mode of beginning the execution of the work would be by conducting the feeders from their source to the reservoir, in order that water might be supplied to every part of the canal as soon as it was executed, and stone, lime, and other materials procured for the works at much less expense than in any other way; purchases of the water rights on Elk creek and much of the land for the feeders were effected, and on the second of May, (the anniversary of the organization of the company), the first sod of the canal of the feeder was cut near Elk forge, and a commencement made in the execution of the work. Since then, contracts have been made for digging, and other measures taken to prosecute the work with such activity as affords a confidence that the whole of the feeder will be accomplished during the present year.

To this detail of the proceedings of the board in their survey may be added the result, which is proved by every circumstance which has occurred to them, that in the case of obtaining an ample supply of water, in the unobstructed nature of the ground, in the excellent position for its terminations, in the shortness of the work itself, and in every other circumstance requisite for forming a canal of the best construction and upon the best principles, the route now marked out is beyond any that has occurred in the history of canal navigation, and seems to be one of those important passes left by nature as an invitation to human art, to establish a monument of patriotism and industry.

From the estimates which have been made by the engineer of the cost of the route adopted, it appears that the work contemplated in its full extent and upon a scale adequate to the greatness of the object, will amount to 560,000 dollars, including the purchase of the water rights, but exclusive of the land. When, however, they contemplate how increasingly important the completion of the canal must become as its progress advances, they have no doubt but that the sums necessary will be furnished, under the power vested in the board, from the completion of the remaining shares, and from the support of the stockholders and the public at large.

Since the establishment of the board additional subscriptions to the amount of about 160 shares have been received, leaving about 500 yet to be subscribed for, to complete the original amount of the subscription of 2,500 shares, mentioned in the acts of incorporation.

The sums of money which the board have received from the stockholders will be sufficiently explained and stated by the account furnished: upon which they have only to remark, that thus far the payments required by the stockholders have been proportioned only to the moderate expenditure of the surveys and the limited progress of the work, and that this expenditure has been regulated by the most strict and methodical economy.

Having thus completed every necessary preliminary, and laid the foundation of a public work, whose utility has never been too highly appreciated, the board has only to commit it to their successors, under the fullest conviction, that if supported by the zeal with which it was undertaken, by the public spirit which is due to its importance, and by the exertion of those places to which it promises the most immediate benefit, its execution will be neither difficult nor its success dubious; but that while it will ever claim for the age and people by whom it was begun, the credit due to those undertakings which almost beyond all others increase the agriculture, manufactures, commerce, and general prosperity of a country, it will afford advantages, perhaps beyond the power of any now to estimate, to the stockholders, to the lands in its vicinity, to the neighbouring states, and to the Union in general."

The second report was made June 3d, 1805.

"Referring to the report presented last year, it will appear, that the survey of the different routes for the canal being completed, and its position determined, a commencement had been made of the feeder, or canal of supply.

Since that period, the work has been prosecuted with unremitted attention, and the following objects have been effected.

Of the whole extent of the feeder, whose length, from its commencement at Elk forge to its junction with the main canal, is five miles forty-six chains and seventeen links, there has been fully completed, fit for the purpose of navigation, three miles seventy-five chains and seven links (nearly four miles;) of the residue, forty chains and sixty-seven links are in various stages of progress, so as to be at least half finished, and one mile two chains and forty-three links is as yet not begun, consisting chiefly of pieces intervening between the parts already finished.

This unfinished work, and the completion of the aqueduct over Elk river, of bridges over three public roads, of one lock and waste weir near the intended reservoir, with sundry culverts and small pieces of masonry, comprises all the operations necessary for completing the whole of the feeder.

These, it is presumed, may be accomplished during the present year, so as to leave the work of the main canal the sole object of the ensuing one.

The cost of all the operations upon the feeder, as exhibited in the general account of the Board now presented, amounts to $59,189.40 of moneys actually paid, and an estimated balance of $17,878.76 on accounts due from the Board, but which could not be adjusted previous to this period: in this expenditure, however, is included a large quantity of stone and other materials for the future progress of the works, and the houses and tools necessary for the operations upon the main canal.

The time necessary for completing the feeder and its expense have been extended solely by the nature of the ground over which it was necessary to form it.—This ground laying chiefly on the east bank of the Elk river, or between Iron hill, Gray's hill, and other high grounds at the head of the peninsula, presented many difficulties; particularly a considerable extent of hard rocky bank only to be overcome by blasting with gunpowder, several projecting points of the surrounding hills necessary to be cut through at a considerable depth, and of a soil uncommonly difficult; and numerous ravines, pieces of low ground, swamps, springs and streams of water, all which required embankments, drains, culverts and other works of considerable labour; these difficulties, more tedious, however, than formidable, or insurmountable in their nature, which could not to any extent be either foreseen, or subjected to calculation—which were absolutely necessary to be overcome, and could be overcome alone by time, perseverance and expense, comprise the sole causes for the protraction of the work, and the objects for which the expenditure of the company's money has been made.

In reviewing these operations, the board has the satisfaction to reflect, that a great quantity of work has been done, comprising that proportion of the great undertaking in which they are engaged, at once the most essential in its kind, and the most difficult in its execution. That the works which have been executed have been done in a manner which will bear the strictest scrutiny or comparison with others of the kind, either in America or Europe, and that the general structure of the feeder is such as to unite the purposes of supplying the canal, and of forming a barge navigation thereto, upon the smallest practicable scale, and at the easiest expense.

In looking forward to the future progress of the work, the board have also satisfaction in observing, that not only has a body of workmen been formed and reduced into system, various preparations, such as houses, tools, &c. made, and an example of perseverance and labour given, but much of the difficulty occurring in the whole undertaking has been overcome, since, at the termination of the feeder, a change of country takes place, which leaves the course of the main canal throughout, free from nearly all the obstructions heretofore encountered, and its expense probably not more, if as much per mile, as the feeder has already cost.

In reviewing the system which the board has adopted for conducting the works, they feel a conviction that its general plan is fully calculated to carry on the undertaking with as much expedition, and as complete a control over the workmen and expenditure, as any they can adopt—they feel sensible, however, that in the outset of a work which was in a great degree new to all the board, in a country very thin in its population, where workmen were to be collected from a distance, accommodations to be provided for them, and their operations to be brought into regulation, the details of that system could not at once be so perfect as they have since become, under the experience gained by the board, or as that experience may still make them in the hands of their successors.

The general account now presented, will show to the stockholders the sums which have been received by the board from the payments already required, and will also exhibit to them the amount of the deficiencies yet outstanding.*

Upon these deficiencies, the board have to observe, that as the whole of the undertaking, and the security upon which the board themselves acted, was the faith of the original subscribers, it was with surprise that they found any persons among so respectable a body of subscribers, who could hesitate at complying with engagements so solemnly made, and upon which such important objects depended; finding, however, that while a large proportion of the stockholders honourably fulfilled their engagements, others delayed them, and some altogether refused, the board found it necessary to take the opinion of counsel respecting measures to be pursued in an event at once so unexpected, and so injurious to their interests; accordingly the opinions of two eminent lawyers in Philadelphia, two in Delaware, and three in Maryland, including the attorney-general, were taken, all of whom declared, that the original subscriptions for stock in the company were recoverable by the direct and usual process of law in all those states.

In this situation, the board had no other alternative but either at once to abandon the interests of the stockholders who had honourably fulfilled their engagements, and suffer the great public work that had been entrusted to them to tumble into ruin; or to avail themselves of the powers which had been given them by law; accordingly, however painful the alternative, yet conceiving it their duty, they directed suits to be brought against the delinquents in all the three states, in consequence of which, nearly all the subscriptions in Philadelphia and Maryland have been settled, but a large number remain due in the state of Delaware.

Except this circumstance, no others have occurred to the board, to depress or lessen the hope of perfecting the works, or the expectations of benefit to be derived from them. In their progress thus far, every thing has appeared to confirm the practicability of their execution: many of the most important difficulties have been overcome. The probability of income to be derived both from the feeder and the main canal has been confirmed, with the additional circumstance, that as the State of New-Jersey is now engaged in opening the communication from the Delaware to the Rariton, this canal will, at the time of its completion, enjoy not only the benefit to be derived from the trade of the two bays, but of extending that trade from the southern to the eastern states, and thus completing one great link in the communication through the United States.

The board are sensible of the gratification which many of the stockholders might derive from an estimate of the whole cost of the future work, but they are the more confirmed at once of the difficulties of making such an estimate, and of the injury which often arises from it, as affording too much ground to those who are disposed to despond, or who may entertain views inimical to the work, by deviations, or the failure of calculations in their nature peculiarly liable to error:—All therefore that they can mention, or that they conceive it their duty to mention, is, that this important work appears to them highly practicable under the same measures they have adopted—that the monies already subscribed appear sufficient to secure the execution of the work, especially with the aid which they are authorized by law to obtain.

For the satisfaction of the stockholders on this head, however, the board will remark, that as every part of the main canal, when executed, will produce a lessening of land carriage, and thereby secure its use, and as the present subscriptions of the company will in all probability finish one end of the canal, and thereby produce a carriage and revenue upon it, so much will be perfected as to make it the interest of the company to secure its future execution.

If the canal be executed from Elk river to the Bear tavern, the land carriage to Christiana bridge will be reduced from thirteen to two miles; and from the traffic already existing by this conveyance, a revenue upon the part so executed, and upon the funds then expended, will be derived, perhaps as great in proportion as upon the whole work when completed, so that there is no doubt but this product will insure the desire and means of the stockholders to effect its completion.

There are other circumstances which aid the expectation that, with a due exertion at present, the work will proceed to a completion. The board are not only authorized to obtain further moneys upon subscription, loan, or otherwise, and these means will be placed in their power by a vigorous prosecution of the work; but there is every reason to expect that the governments of the several states bordering upon the canal, and that of the United States itself, will support a work promising such great public advantage.

In order to avail themselves of this aid, and of that confidence which public support adds to a work of this kind, applications were made by the board to the legistures of Delaware and Pennsylvania, in both of which, resolutions were passed for subscribing to the canal; and though the acts for that purpose were not completed during the late sessions, owing to the great quantity of previous business before the several houses, yet there is every reason to believe they will be passed in the ensuing sessions, and that the legislature of Maryland will adopt the same measures.

In order, however, to receive this aid, and indeed to entitle the company to it, it is necessary that the works should proceed with unremitting exertion through the present summer, that all idea of despondence should be laid aside, and that the stockholders should give that support to the undertaking, which can alone enable the future direction to carry it into effect.

If ever this work, thus favourably begun, and so considerably effected, should suffer injury or delay, this reflection will justly arise, that it is neither from the impracticability of its execution, from the greatness of its importance, nor from a want of zeal and perseverance in those to whom it has thus far been intrusted, but from a despondence without cause, from a versatility to abandon an enterprise just as it is begun, and from that want of public spirit and fortitude, without which no public work whatever can succeed.

Having thus exerted themselves in the performance of their duty during the period for which they were elected, and given to the stockholders and to their successors the best information as to the past, and prospects of the future, which is in their power to bestow, the board have only to resign into the hands of those stockholders, and to the direction they may appoint, the future fate of this important work, with every hope for its success.

Signed by order of the Board.

By the report of last year, the stockholders will perceive, that the operations of the company had been directed, thus far, to complete the feeder or canal of supply, of which there then remained about one mile unfinished, and that it was the expectation of the board that the same might be completed during the late year, and the main canal itself begun in the course of the present one.

But the exertions of the board in this respect have been wholly disappointed by the delinquency of the subscribers; this delinquency was stated in the last report; a hope, however, prevailed, that a sense of public duty, in supporting a work of such general and acknowledged utility, or at least a regard for private honour and good faith in performing engagements solemnly contracted, would have produced the payment of those arrearages, upon which the progress of the work depended. But unfortunately, so far from these hopes being realized, the failure of payments among the remaining subscribers became so general as to leave no alternative but the prosecution of suits against the deficient parties, and suspension of the work until legal justice should furnish the funds which the defection of individuals had retained.

In justice, however, to those stockholders who have honourably fulfilled their engagements, it is incumbent on the board to mention, that but a small proportion of delinquencies exist in the city of Philadelphia or in the state of Maryland, that a respectable number of the stockholders in Delaware have also paid, and that the deficiencies chiefly exist in that State and in the vicinity of the canal, where, above all others, they should have been been least expected.

To assign any other cause is at once obviously unnecessary and impossible, for from this alone has the suspension of the work arisen, since the payment of the arrearages now due would have completed the feeder, enabled the board with propriety to draw forth the residue of the company's funds, and left the execution of the canal no further a subject of doubt or despondence.

In order that no means should be left untried, which it was in the power of the board to attempt—applications were made during the late winter to Congress, and to the respective legislatures of Pennsylvania and Maryland, impressing on them the importance of the canal as a great national work, interesting, more than any which could be contemplated, to those states, and to the Union at large, and praying that as such the company should receive their patronage and support.

These applications were all favourably received, and the importance of them recognised both by Congress and the state legislatures, in their respective acts and reports.

The house of representatives of the United States, after fully admitting the importance of the canal as a national work, especially as a means of defence during any hostile act, plead the pressure of demands on the public funds for withholding a present grant of money—in the senate a resolution was introduced for granting a considerable quantity of land in the Western Territory.

In the legislature of Maryland, a resolution was reported by a committee of the house of delegates for authorizing the treasurer to subscribe for one hundred shares, and a bill was reported by order of the house of representatives of Pennsylvania for a like subscription to an undefined number—after this recognition of the principles and importance of the work, and a reception so highly favourable and flattering to the hopes of the company, as to leave little doubt of success at a future session, it was with regret the board perceived, that from the pressure of other business, the several resolutions and acts were unhappily postponed for the present, so that none of them were carried into an effect so complete as to render any immediate aid for continuing the work.

Thus the want of public support, which appeared the only resource on the failure of payment in the subscribers, has confirmed the present suspension of the canal: with what concern the board view this event, the public can estimate: without arrogating to themselves any merit beyond the fair execution of their duty, they feel it no more than an act of justice to remark, that, partaking of the general zeal which was manifested at the first institution of the company, they entered upon the execution of the trust committed to them, and have persevered in an arduous attention to it through a course of three years, under a firm reliance on the punctual payment of the subscriptions as the work should require them, and on a continuance of that zeal and public support under whose auspices they began, and which was essential to animate and encourage them through all its progress; their regret therefore is in a high degree accumulated from finding themselves deprived of means to proceed, and the works suspended in their hands, not by a failure of their own attention, but of that support on which they were taught to rely.

That the regret which the board experience will be participated by every patriotic mind, who originally felt the importance of uniting the two bays of Chesapeake and Delaware by an uninterrupted navigation, or who now feels that importance confirmed by the ease of executing it, is a subject of some consolation, and affords the hope, that the lassitude or negligence of the public mind to an object at once so new, so useful and interesting, for which so much concern has been professed, and so little realized, will soon be succeeded by that just attention to their interests, which a large proportion of the United States, and particularly the country contiguous to the canal, ought to feel."*

We have now given, as far as the limits of our work would admit, views of the general advance of artificial inland communication in the United States, north of the Susquehanna; and now proceed to review those of that stream, and those more southward.

Two small canals already exist on the Susquehanna, one in Pennsylvania, at the Conewago falls, and the other in Maryland. The former, by a fall of 19 feet and 1 mile in length, passes those falls, and the latter, called the Susquehanna canal, reaching from tide water to the Maryland and Pennsylvania line, passes the Lower Falls.

The practical experience of Mr. Latrobe, and the boldness and justness of his conceptions, give his observations great weight, and from his intimate knowledge of the country from the Susquehanna to the Roanoke, inclusive, his geographical sketches deserve peculiar attention, and ought to be preserved; we therefore make the following extracts from his report to Mr. Gallatin, when secretary of state, March 16th, 1808. We have been induced, also, to give this report to our readers, as it contains invaluable advice respecting some prevalent errors on the subject of canals, and, in particular, a much too strong predilection in favour of natural channels in general, and too little regard to the many insuperable advantages, in most cases, even in point of expense, in favour of artificial canals.

"Two principal objects will dictate all the exertions towards the improvement of our internal navigation, which can, for many years to come, be attempted: 1. To carry our produce by water to the nearest port for its exportation, and the importation of foreign articles. 2. To exchange, by internal commerce, the articles reciprocally deficient, on lines parallel to the sea coast. Canals, the use of which arises from manufacturing activity, will not probably be soon required.

The first object,—as all our principal rivers run seaward, and generally by the shortest course,—must be attained by the natural or improved navigation of the rivers themselves, or by canals cut parallel to them; the second may often require a navigation parallel to the valleys, so as to communicate one principal river with another.

The former attempt at improved navigation has already been made on many of our principal rivers,—the latter has been seldomer undertaken; and only once above the falls of both primary rivers, in the canal intended to join the Susquehanna and Schuylkill, and the Schuylkill and Delaware rivers above Philadelphia.

The general construction of our country opposes to artificial navigation, in either of these directions, difficulties, which, in no part of the world, exist in so uniform and certain a degree. Canals, parallel to our rivers, have three formidable obstacles to encounter and overcome:

1. The rapid descent of the ravine cut through the mountains by the river itself, along which the canal must be carried; or, if the ravine be quitted, difficulties on the high levels, which, the further you go from the river, are always intersected by the more numerous ravines, and embarrassed by the difficulty of returning to the ravine of the river.

2. The invariably rocky nature of the ground, which is uniformly of granite, in all its varieties; and has numerous fissures, which carry off the water, and require lining.

3. The difficulty of keeping off the land water, and of crossing the lateral branches and torrents of the river.

On the other hand, canals, parallel to our mountains, must necessarily cross the ridge or spur of the mountain which divides the waters of two primary rivers. On this ridge, above the falls, the water requisite to supply the canal is always scanty, often there is none; and though a tunnel or a steam engine, or, in the last resort, a rail road, are certain means of obviating the difficulty, they are expensive, inconvenient, and imperfect. Below the granite ridge, the difficulty is less. There may always be found a supply of water from the ridge itself; and the feeders, though carried through rocky and expensive ground, are themselves useful as small canals, as far as they extend; and below the ridge the soil is easily cut and embanked.

Having so frequently mentioned the granite ridge, I will here trace its extent, as far as my knowledge of our country enables me do.

The granite ridge forms the shore of the north side of Long Island, opposite to the island of New-York. All the south of the island is alluvial, and is the first margin of alluvial soil below the granite ridge. This margin of alluvial soil, beginning at Long Island, widens as it extends to the south-west, until in Georgia it becomes more than 200 miles in width.

Staten Island and Bergen Point, are two spurs of this same ridge, which continues nearly in the line of the post road to Trenton, where the river Delaware falls over it, having worn down the rocks more deeply there than many other of our rivers. The Delaware runs in its general direction for 60 miles under the ridge, as far as New-Castle, leaving it only for a short distance at particular bends of the river. At Philadelphia the ridge crosses the peninsula to Gray's ferry, on Schuylkill. The softer granite of Schuylkill has been worn down so that the falls are 4 miles from its lower edge. From Philadelphia the ridge runs with the post road to Havre-de-Grace, where it is visible on both shores, although the tide extends 6 miles above, to the foot of the falls.

The Susquehannah, by the name of the Chesapeake, may be considered as running under the foot of the granite ridge, almost as far as Baltimore, which city is built upon the foot of the ridge. At the river Patuxent, on the post road, the ridge appears again, but is lost under the incumbent soil, and is not again visible until it appears at Georgetown. The harder granite of the Potomac has resisted the force of the water more than the granite further to the north-east, and the tide reaches only 3 miles above its outrunnings. From the Potomac, the falls of Rappahannoc at Fredericsburgh, of James river at Richmond, Appomatox at Petersburg, Roanoke at Halifax, beyond which point my personal observation does not extend, point out the course of this ridge in a line nearly parallel to the Blue ridge, diverging to the eastward as it extends southward.

The difficulties of the natural navigation of our rivers are: In spring,—the danger of wreck in the wild water of our rapids; in autumn, obstructions created by rocky shoals; and, in most of them, rapids and falls impracticable at all times. The least expensive and most obvious means of removing the former, are the blowing of the most prominent rocks, so as to straiten the channel, and procure a passage at low water. This has, in almost all our rivers, been attempted on a greater or less scale, and with various degrees of success. When injudiciously performed, and in rivers of rapid descent, and liable to great variation in the quantity of their water, more injury has been done than advantage obtained. Many of our worst obstructions act as natural dams, which, holding up the water, create a large extent of excellent navigation above them. Of this, the James river, above Westham, and the Susquehanna, above Chickisalunga and Hunter's Falls, are instances in point. Such obstructions, when removed, let down the water rapidly from above, without supplying deeper navigation below.

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* Gilpin, p. 49-70.

In a river of such magnitude as the Susquehanna, indeed, no gap or sluice artificially cut can materially affect the rapidity of the stream; but, in lesser rivers, great care is required, not only to prevent lowering the water above, but to avoid giving a new direction to the current, more mischievous in its effects than that which has been changed. But, with whatever judgment the natural navigation of a river, perplexed by rapids and shoals, may be conducted, and however its descent may be thereby facilitated, its ascent cannot possibly be rendered more easy, in the same degree. Thus, for instance, although by the moneys expended by the state of Pennsylvania, and the Susquehanna Canal Company, on the natural navigation of the Susquehanna below Wright's ferry, it has been rendered much less dangerous to run down the distance of 41 miles, almost the whole of which is a tremendous rapid, from Columbia to the tide, and thereby to carry lumber, iron, and agricultural produce to Havre-de-Grace, and thence to Baltimore,—yet so difficult is the up-stream navigation by the same route, even with the assistance of the Susquehanna canal, that the returns in imported articles have been generally purchased in Philadelphia, and conveyed to Columbia or Middletown, above the rapids, by the Lancaster turnpike, thence to be boated to the country watered by the upper branches of the Susquehanna. And, although the Philadelphia market has hitherto offered more advantages to the buyers of imported goods than that of Baltimore, yet the expense of transporting them 72 miles by land to Columbia would, if there were a good navigation from Havre-de-Grace upwards, destroy this advantage.

The difficulty of carrying canals parallel to our great rivers, the scarcity of engineers possessing knowledge and integrity, the want of capital, and, above all, the erroneous dread of bold measures, and the fear of uselessly expending money among us in works hitherto unknown among us, have deterred those interested in improving our navigation from deserting the beds of our rivers, while it was practicable to keep them. They have therefore had recourse to canals only where navigation was otherwise impossible, where obstructed by rocks, or broken by a cascade.

There cannot, however, be a reasonable doubt, that, if in England, where, compared with the United States, the quantity of water in the rivers varies little between the driest and the wettest period of the year, a canal running parallel to a river furnishes a much more certain, and safe, and equal, and cheap navigation than the river itself—it is infinitely more the case here. Unfortunately, those of our canals which have been cut to pass the rapids and falls of our rivers partake, in a great measure, of the inconveniences of the rivers themselves; some wanting water when the river is low, some incapable of being entered, excepting at a particular height of the water in the river, some subject to constant accumulation of bars, and all of those with which I am acquainted, much less useful than the money expended on them ought to have made them.

Those canals of which I now particularly speak, are the James river canal, the Potomac canal, the Conewago and Susquehanna canals. Of the canals north of the Delaware, and south of Virginia, I have not sufficient knowledge, nor can I speak of the Appomattox canal. It is, I believe, not liable to the same strictures, in all points, which I shall make upon the others; but, though I am well acquainted with the ground, I have not seen the manner in which the work has been executed.

One great and fatal error has been interwoven into the scheme of the other canals, excepting only that of the Potomac. They have been dug as much with a view to the erection of mills, as to the purposes of navigation. To fit them for mill races, their descent is rapid, and their current strong. They are liable, of course, to the variation of the quantity of water in the river; they bring down with their current alluvium of the river; bars are formed in them, as well by this alluvium, as by the land wash; and their banks, where they are not of rock, or walled, are liable to perpetual wear by the current. The canal is, besides, itself an inconvenient rapid to those who would ascend it.

Besides these inconveniences, the contracts, binding the company to furnish to the millers the water, when it rises above a certain gage-selle, for an annual rent, or on other fixed and permanent terms, tie the canal company to the original construction of the work, and forbid future improvement. For instance, if a lock were found to be useful above the highest mill, it could not be erected, because it would rob the mills below of their stipulated water; the inclination of the canal cannot be lessened, because it would have the same effect. In the James river canal, more than in any other which I have seen, this error, though now generally considered as a very great advantage, will, at some future period, be discovered and deplored. The Potomac canal, more especially that of the Little Falls, has the same defect of a too rapid descent, although the object of a mill race is placed, by their charter, out of view. But its principal defect is of another kind, to which that of James river is also, but in a less degree, subject. It receives the wash of all the hills and ravines of the north bank, which ought to be discharged through culverts, or carried over bridges: and that legislative impartiality, which has required the canal to enter the river at the very head of the tide, in order that Virginia may have an equal chance of becoming the depot of its commerce with Maryland, has very much injured its utility to the country at large.

In a still greater degree than the Potomac canal, the Susquehanna canal, beginning at the Maryland and Pennsylvania line, and ending at the head of the tide, has the defect, not only of receiving the land wash of the hills and ravines, but also two considerable rivers, the Conewingo and Octorara, partaking thus of all the danger arising from their inundations, and receiving their alluvium. This canal is also applied to the purposes of a mill race. Other inconveniences attend it, which arise from the most unfriendly nature of the river, and the local feeling of the state legislatures of Pennsylvania and Maryland, at the period of the incorporation of the company.

The Conewago canal, about 50 miles higher up the Susquehanna, is also a mill race, and is the property of an individual. It is of difficult entrance, which is to be regretted, as it ought to be the means of passing a short but very dangerous fall of the river, which interrupts a long extent of very good navigation.

Having thus pointed out the general and common defects of these canals, to which I may add the general want of proper slopes to their banks, I will now enter upon the very thankless task of giving an honest opinion respecting them, in detail, viewing only the *public interests*, and perfectly conscious of the bearing of what I shall say upon private feelings. These feelings, however, are extremely short-sighted; for nothing could be more advantageous to the individuals most interested, than those measures which would most benefit the public.

The James river and Appomattox canals stop short of tide water. The most important of these canals is that of James river. Upon the coal mines of James river, our Atlantic sea ports will soon become dependent for their chief supply of fuel. That dependence exists already, in respect to the fuel required for a variety of manufactures; and even now, the smiths within ten miles of our seaports require, in order to carry on advantageous business, a supply of Virginian coal. There are three means (and I think only three) by which the Virgian coal can be brought to the tide. 1. By a small canal and rail roads, immediately from the mines south of the river to the shipping tide water at Ampthill, or its neighbourhood, along the valley of Falls creek; distance, I believe, 20 miles. This is a route easily practicable, and at a moderate expense, for Falls creek rises in the coal mines themselves. 2. By the turnpike road to Manchester, opposite Richmond. This road has been some time completed, and is of the highest utility. 3. By James river to the head of the falls, and thence by the canal to Richmond. This is, for two-thirds of the coal country, the best and most obvious route. For, from all the mines, the coal may easily be brought to the river on rail roads, and thence boated, independently of the cheaper conveyance which Tuckahoe creek might be made to yield to a great extent of coal land now little worked. But of what adequate use is this navigation in boats carrying, at an average, 200 bushels of coal only, when, if the canal were well constructed, 1000 bushels might be as easily and cheaply conveyed; and when, on their arrival in Richmond, they must be unloaded, again loaded into carts, and carried down, by a bad road, to the tide at Rockets, to be shipped? The Manchester turnpike, with all its expense of waggons, horses, and drivers, and the consequent waste of *labour*, *capital*, *food*, and *forage*, is a better, and, I am told, as cheap a mode of conveyance.

The means by which the canal itself may be made much more useful, I will not consume your time and patience in detailing; what is most important, taking the whole subject into view, is, to connect the canal, such as it is, with the tide.

In the year 1796, Mr. Weston, then engineer to the western navigation companies of the state of New-York, was called to Richmond, to give his advice and opinion on this subject. It amounted to this: to connect the basin with the foot of the falls, by a succession of ten or eleven locks in one tier, carrying the race of Ross's mill upon an aqueduct across the canal at the foot of the locks. With all deference to his talents, I cannot help remarking, that, of all expensive projects of which I ever heard, this would have been one of the most useless. For, independently of the excessive inconvenience and detention which such a tier of locks, at the most busy part of a navigation, would occasion, the boats would arrive at their foot, in a very considerable rapid, now impracticable, and which could only be made practicable by blowing up the rocky bed of the river. When arrived there, two miles of tide water must be encountered; to navigate which, these boats are wholly unfit. I cannot help thinking that the present mode of conveying the coal to Rockets is not much less eligible. I refrain from stating many other objections, which are professional, and which, I believe, were, as well as those already mentioned, as evident to Mr. Weston as to myself; but objections of a another nature, more powerful than mere physical difficulties, opposed every project, excepting that which he proposed.

In order to connect the basin of the James river canal with the tide, a very simple means is offered by the nature of ground. To do this it will be necessary to form a capacious basin at Rockets, communicating with the tide by one or more locks. To carry a canal from thence along the level bank of James river to Shockoe creek. A cheap aqueduct of one arch of 30 feet span will carry the work across the creek into the back street. The canal will then go up the back street, mounting by successive locks, not more than two in each tier, into the basin. The canal from Rockets to the basin on Shockoe hill should be of 9 feet draught of water, and the locks 100 feet long and 18 feet wide. This canal would of course bring vessels which navigate our coasts and bays, and run out to the West India islands, into the basin on Shockoe hill.

The legislature of the state of Virginia (for the commonwealth is deeply interested in the stock), has from time to time expressed great anxiety on the subject of completing this canal. But the dread of unforeseen difficulties and risks in carrying the work below the basin, and the value and productiveness of the stock in its present state, have hitherto overbalanced this anxiety. But, considering Richmond as the principal source of fuel to the cities on our sea coast, at least until the mines of cape Breton shall supply us, I feel a national sentiment, in deeply regretting the very fatal policy which maintains and supports the error, and the mutilation of this most important work. I will not at the same time deny, that when it is considered that those who projected and executed the canal were men of no acquaintance either with general science, or with this particular branch of art, and knew nothing of canals but from books or hearsay, they have already done wonders. They deserve the thanks of their state, and of the union. But the work should not stop where they have left it. Nature has, perhaps, done more for Richmond than for any site where a city has been planted. For 10 miles above the city on both sides, and upon several islands of the stream, there are innumerable mill seats, supplied by one of the noblest rivers in the union. Immediately above the head of the falls lies an inexhaustible treasure of coal. Every art and manufacture to which human ingenuity can employ fire and water, may be here carried on with the least expense. From above, an easy and wide spreading navigation collects on this spot all the raw materials which our climate can produce; below, a river capable of bearing sea vessels sufficient for every trade but that across the ocean, is ready for the exportation of its merchandise. The town itself is placed on a healthy and commanding ground. But to improve these advantages to the utmost extent to which our population is equal, nothing would so much contribute as the completion of the Richmond canal.

I have dwelt specially on the coal trade to which this canal is subservient, as of first rate national importance. It is of no less importance to the state of Virginia as a means of conveyance of agricultural produce. As you will receive an answer in detail to your queries relative to the amount of all the sorts of produce carried upon it, and of its actual trade, I will not add any thing further to what I have already said on the subject, but to observe, that at some distant period the Chickahominy, a river rising in the coal country, and discharging itself into James river below Richmond, where ships may take in their cargoes, offers a means of carrying down the coal destined for distant exportation.

A canal has often been projected for passing the falls of the Rappahannoc at Fredericksburg. There is no reasonable hope, however, that this work can soon be executed. The ravine of the river at the falls on either side is so abrupt, rocky, and irregular, that great expense must be incurred to effect it: an expense not likely to be repaid by its trade for many years.

A canal to connect the Rappahannoc with the Potomac, a few miles below Fredericksburg, across the northern neck, has also been spoken of. It would be a highly useful work, but would require a tunnel of 2 or 3 miles. I believe it could be executed at an expense not greater than the tolls would remunerate. Such a canal, however, does not belong to the class of which I am now speaking.

The Potomac canal consists of two parts; one to pass the Great falls, 14 miles above Georgetown, the other to pass the Little falls. The errors committed in the construction of the work have been enumerated above. The trade of this canal, especially during the year 1807, has been so great that there appears every prospect of its becoming a productive work *in those years* in which there is a considerable and equal quantity of water in the river. But upon this circumstance it must always depend. The information respecting it, which can be obtained from the company on the spot, renders it unnecessary for me to say more upon it.

No attempt at the improvement of the navigation of any of the rivers of Maryland, between the Susquehanna and the Potomac, has been made, nor is there in the prospects of advantage to be derived from the navigation of the two Patuxent, the Patapsco, or any of the lesser rivers falling into the Chesapeake, any thing which could at present tempt capital into such an undertaking.

But the Susquehanna itself has been for many years the object of almost all the attention directed in the states of Maryland and Pennsylvania to the improvement of our internal navigation. About six miles above Havre-de-Grace, this mighty river meets the tide. The place is now known by the name of Smith's ferry. The map of the river from thence up to Wright's ferry, (Columbia) in Pennsylvania, which I made in the year 1801, when directing the works carried on for the improvement of the natural bed of the river, and which, by favour of the governor of Pennsylvania, I am able to exhibit with this memoir, will explain the nature of this part of the river very minutely, being drawn to a very large scale. The whole of its extent is one tremendous rapid, which in fact continues to the north-west side of the Chickalunga hills, 3 miles above Columbia. The rapid is not every where of equal velocity, or equally dangerous. Wherever the river crosses a valley of limestone or slate, the rocks are worn down into a smoother and wider bed: but when it has to cross a ridge of granite, its course is immediately broken by irregular masses and ranges of rocks; its bed is narrow and inclosed by precipices, and its torrent furious and winding.

The Chickisalunga falls can be descended without danger, and no attempt to open them has been thought necessary. The ridge of granite hills through which they break bounds on the north-west the beautiful limestone valley of Columbia. Across this valley the river runs rapidly, but smoothly. Another narrow ridge of granite hills crosses the river immediately below Columbia, over which the river falls rapidly, and then enters the wider limestone valley, known by the name of the Jochara valley. The river spreads here to the width of three miles, its stream is gentle, though rapid, and it abounds in beautiful and fertile islands. It then suddenly contracts, and is received into the narrow ravine which it has *sawed* down in the granite hill called Turkey hill. From its first entrance into the Turkey hill, to the tide, there is no part that deserves the name of a sheet of smooth water. When the river is full, the whole ravine about half a mile in width contains only one furious torrent, in which few rocks comparatively are to be seen above the water; but the danger is not the less, and very skilful pilots and many stout hands are required to carry a boat or an ark safely down. But in the autumn, and in a dry season, the river itself can for six miles scarcely be seen, and its bed appears a barren and dry waste of irregular rocks, among which the loud roaring of water is only *heard:* for, from the Turkey hill to near the mouth of Conestogo, the whole river is discharged through a channel generally about 60 feet wide, in the greatest part of which the depth and the rapidity of the torrent is such, that it has not been fathomed. About a mile below the mouth of Conestogo, a narrow limestone valley touches the river on the north-east side, but on the west shore not a trace of limestone is to be seen. Four miles below Burkhalter's ferry, the river arrives at the high range of granite hills, abounding in copper, in which the gap mine is situated, and at a place called M'Call's ferry, it narrows to the width of 16 perches. Here I attempted to find bottom with a line of 180 feet, but failed, notwithstanding every precaution taken to procure a perpendicular descent of the weight attached to it. Through this pass the water is rapid, but smooth and safe. The river rises here rapidly and very suddenly after the fall of rain above; and it will never be possible to erect a safe bridge at this place, so often mentioned as the most practicable. The obstructions to navigation by three rapids, below M'Call's, is not so considerable as to endanger the arks and boats that descend, until they arrive at Baldfriar falls, below Peachbottom, and about 8 miles above the tide. From M'Call's to the slate valley of Peachbottom, the river is filled with islands called the Bear islands. Across the valley of Peachbottom, and above the Baldfriar falls, the river is wide and safe. The best natural navigation, and that always pursued by boats descending by the natural bed of the river, is on the west side, from the foot of the Bear islands. Above that point to Columbia, the best passage is on the east side. The most dangerous falls below Peachbottom were Amos's and Hector's falls, on which many wrecks annually occurred until the late improvements of the navigation were made.

From this description it may easily be imagined, that if the descent of the river with boats loaded with produce was dangerous and difficult, the ascent was still more so. The natural obstructions were besides increased by fish-dams in every part of the river, and the rival interests of the states of Pennsylvania and Maryland prevented, for many years, every attempt at artificial improvement of the bed of the river. In the mean time each state took measure to go as far towards rendering the navigation of this river useful to their respective interests, as their means and limits would permit; and a company was incorporated in Maryland to make a canal from the Maryland line to the tide, to pass all obstructions of the river of the eight lowest miles; and in Pennsylvania two companies were also incorporated, the one to connect the Susquehanna with the Schuylkill, by a navigation taken out above all the dangerous falls, the other to connect the Schuylkill with the Delaware. The objects of none of these companies were advantageously accomplished. The Susquehanna canal company have, however, completed a navigable canal, liable to the objections which I have above noticed. The Pennsylvania companies have made considerable progress in the works, under the direction of a very able engineer, Mr. Weston, but have not completed either canal so as to render them useful or productive.

At last, in the year 1801, the states of Maryland and Delaware having passed laws incorporating a company for the purpose of cutting a canal between the Chesapeake and Delaware, a former law of Pennsylvania, appropriating 10,000 dollars to the removal of obstructions in the Susquehanna, went into effect; and the late colonel Fred. Antes, than whom no man was better fitted to accomplish its object, was charged with its execution. But he died on his arrival at the river, and the direction devolved on me. The enclosed report to the legislature on this subject details the extent of the work executed, and the principles on which I proceeded in the attempt to make a practicable and safe navigation both up and down the river. I will here only repeat, that all my exertions were bent to force through all obstructions, a channel clear of rocks, of 40 feet wide, close to the eastern shore, never leaving any rock upon which a vessel could be wrecked between the channel and the shore, so that in the most violent freshes a boat should always be safe, by keeping close in shore. Rocks of immense magnitude were therefore blown away, in preference to the following a crooked channel more cheaply made, but more difficult and dangerous, and varying in safety and practicability, according to the degree of the rise of the river. There is however one part of the navigation in which the bed of the river must for ever be pursued, namely, from the Indian steps above M'Call's to below the gap at M'Call's:—a part of the navigation which, if art can conquer it, must be undertaken in a state of the country infinitely more abounding in wealth and population than at present."

But little remains to add, to complete our general review of the inland navigation of the United States; but we are compelled, from the magnitude of the project, to dilate partially on the long contested and investigated problem of a canal line or lines through the Appalachian mountains, connecting the basins of Susquehanna and Roanoke with the valley of Ohio, and the basin of Susquehanna to Cayuga lake. Respecting the latter communication we regret to be unable to convey any specific facts, but from respectable sources of information are inclined to consider the enterprise practicable.

To effect the former object, the following channels have been proposed. The west branch of Susquehanna and the Juniata in Pennsylvania; the Potomac, James river, and Roanoke, in Maryland and Virginia.

Of these routes, it is probable, neither can be effected without incurring very heavy expense. The peculiar gorge through which the grand western canal of New-York has been carried, we have noticed and described. Without paying attention to the mountain ridges, the table land on which they stand rises gradually from the valley of the Mohawk south-westwardly, and, as we shall soon see, has reached at the mouth of Savage river on Potomac 1160 feet. The Rome summit level it may be remembered we stated at 420 feet, consequently the table land from Rome to the mouth of Savage river has gained an elevation of 740 feet.

No level has ever been drawn over the intermediate country to determine the rise and fall by the route of the West Branch and Allegany rivers, but from the elevation of the Susquehannah at the mouth of the Swatara, the summit level near Coudersport must greatly exceed that near Rome. An actual communication by water has long since on a small scale been effected by a gentleman of the name of Freeman, but too little mathematical and statistical information of the country has been collected to permit a decisive judgment upon it as a route of inland navigation.

The Juniata, though to a considerable distance navigable, may be nevertheless, for purposes of canal communication between the waters of Susquehannah and Ohio, pronounced utterly impracticable.

The Potomac, in Maryland, and Monongahela, in Pennsylvania, seem, from their relative position on a map, to form the most naturally direct channel of communication which exists between the basin of Susquehanna and valley of Ohio; but the subjoined table of heights will exhibit formidable obstacles to canal improvement. Commencing at Washington City at tide water,

	Miles.	Rises in Feet.
From tide water to Great Falls - -	12 -	143
Great Falls to Shanandoah - - -	40 -	39
Shanandoah Falls - - - - - - -	5½ -	43
Cumberland - - - - - - - - -	130½ -	490
Mouth of Savage river - - - - -	31 -	445
	219	1160

From Savage river to Pittsburg, is by a direct route over the mountain valleys, and thence by the channel of the Monongahela, about 120 miles; or by the channel of Youghiogany is 90 miles to Pittsburgh, and by either, a fall of 905 feet. From these elements, the rise and fall from tide water in the Potomac to Pittsburg in a little more than 330 miles amounts to 2065 feet; demanding 206 locks at an average of 10 feet lift. If we subtract from this 40 or even 50 miles in the Monongahela, where locks may not be needed, it would only lessen the extent of lockage at most 100 feet, and still leave a rise and fall, where locks would be indispensable, of 1965 feet.

Thus, though the City of Washington is the nearest seaport to the head of uninterrupted navigation in the valley of Ohio, whether the relative distances are taken in straight lines or along the intermediate streams, yet from the great intervening elevation, all rational ideas of profitable canals may be abandoned, in the present state of science, population and wealth in the United States.

Much has been done to render the inland trade of the Potomac itself commodious. In the District of Columbia, at Georgetown, the tide is arrested by the Little Falls; here, as may be seen by reference to Mr. Latrobe's report, a defective canal has been constructed 2½ miles long with 3 locks. At the Great Falls another canal descends 76 feet in 1 mile by 5 locks. Seneca falls, 6 miles above which descend 10 feet, is also passed by a short canal. From the latter point to the passage of the river through the Blue Ridge, the river is open and navigable in its natural state. At and near Harper's ferry great obstructions existed in both the Potomac and Shenandoah; these have been partially obviated by canals, and the fine upper valleys on both streams laid open to the commerce of the Chesapeake bay. Immense quantities of grain, flour, whiskey, and other produce is annually brought down: the port of Alexandria is the general depot of this valley of inland trade.

The canals of Virginia have been noticed by Mr. Latrobe; we can add but little to his stock of general information, and have no room for more extended detail on the subject, but we consider ourselves bound to notice another project of inland navigation which has long occupied the attention of the people and legislature of Virginia, that is, a connexion between the Atlantic waters of the state and those of the Kenhawa branch of Ohio.

A board of public works exists in Virginia, which, in 1819, had a fund at its disposal yielding a net revenue of 126,441 dollars. In that year large grants, amounting to about 300,000 dollars, were made by the legislature to aid in the internal improvement of the state, and on January 25th, 1820, Mr. T. M. Randolph, president of the board of public works, made the following report:

The president and directors of the board of public works, in obedience to the resolution of the general assembly of the 26th of February last, requesting them "to report to the (then) next general assembly, the best practicable communication, for the purposes of trade between the waters of James river and those of the great Kenhawa; together with an estimate of the probable expense of such plan or plans as they may suggest," having caused surveys of those water courses and the intermediate country; and estimates of the expense of making a communication between the basin at Richmond and the Ohio, which might be convenient for the purposes of commerce, to be carefully made by their principal engineer and Isaac Briggs, as suggested in the last annual report; and having received the report of the former on the 14th day of this month, and of the latter on the 19th inst. now submit those reports to the consideration of the general assembly; together with the result of their reflections and deliberations thereon.

It is deemed superfluous to insist in detail, upon the many weighty political, commercial and local considerations which ought to influence the public councils of the commonwealth, in giving every practicable facility to the accomplishment of this great internal improvement. Those details may be found, in part, in the report of John Marshall and his associate commissioners made to the legislature of Virginia in the year 1812; in the several reports of the board of public works, heretofore made to the general assembly; in the report of Samuel Blackburn, made to the present assembly; and in the reports of the engineers accompanying this. To all which, the general assembly are respectfully referred. The board of public works, however, in looking as they do to the profits which will speedily accrue upon the proposed works as they progress, as the means, and, if they are not greatly mistaken, ample means of completing by far the greater portion of those works, are necessarily led to the examination of the present state of the agricultural and mineral products of that part of Virginia which is naturally and necessarily connected with the proposed improvement; and the probable effects of such improvement on these subjects. The coal trade of James river labours under great disadvantages, for the want of a cheap mode of conveyance, which the present state of navigation of James river does not afford; the coal comes into the market, not only charged with the burthen of 12½ cents per bushel for carriage, but, in consequence of the mode of transporting it, it is greatly deteriorated and disfigured.—The effect of which is, that the English coal, although charged with a heavy export duty in England; a heavy import duty in America; and a freight across the Atlantic, comes advantageously into competition with the James river coal, in the principal Atlantic sea port towns in the United States, and even in Norfolk; so as, in a great measure, to exclude the James river coal. The proposed improvement would not only release the coal of James river from two thirds of the charges of transportation to Rockets, (for it would have a right to pass through the smaller locks of the dock company without paying toll), but would bring it into market uninjured by the transportation; under such circumstances it is impossible but that the British coal must yield the American market to the James river coal.—That market is already great, and is becoming daily more important. The stock of coal on James river is supposed to be inexhaustible; and it may be justly anticipated, that in ten years after the James river coal shall have come fairly into competition with the English coal, from five to ten millions of bushels of the former will pass the proposed canal. Such an anticipation, however, is not at all necessary to justify the proposition which the board of public works are about to submit for the improvement of James river. They disclaim all speculative views, and found themselves on the trade, which, under existing circumstances, must necessarily pass through the canal in contemplation.

The board of public works are assured, and do not doubt the fact, that at present 500,000 bushels of salt, made upon the banks of the Kenhawa, are annually exported by contract through that river:—That much larger quantities would probably be made, and transported through that channel, if the makers of salt were not prohibited by the terms of an existing contract, which is temporary, from exceeding that quantity: That the salt wells of the Kenhawa afford water of a quality much superior in strength to that of any other salt works which can come in competition with those of the Kenhawa: And whilst all other works depend on wood for fuel, which daily becomes more scarce and costly, the Kenhawa works have an inexhaustible supply of fuel, in bodies of coal in their immediate vicinity. That there is, besides the exportation of salt, a great commerce on the Kenhawa, in articles for the supply of the salt works, to wit. Lumber, provisions, groceries, and various merchandise; but that, when the river is low, especially as it has been for many months past, that commerce is greatly interrupted, and the persons engaged in it suffer great loss and inconvenience, which would be completely removed by the proposed improvement. With a good navigation on this river, it is hardly possible to anticipate the extent to which the commerce on it would be carried.

A great extent of country upon the head waters of James river, and on the New and Greenbrier rivers, abounding with fine timber, iron ore, and other minerals, and well fitted for agricultural purposes, lies almost unoccupied, because the products of the country will not, under existing circumstances, bear the cost of transportation to market.

The execution of the proposed improvement would have the effect of bringing the whole of this extensive country as near to market, in respect to the price of transportation, as Albemarle county now is; would soon people and bring into cultivation this great extent of territory, and the produce drawn from them, together with that which would be drawn to the canal from a greatly increased distance on both sides of James river, might justly be expected at no distant period to double, treble, or quadruple the trade on the canal. If, therefore, nothing were due to the more enlarged political and commercial considerations connected with this subject, it would seem that local considerations alone would afford a sufficient inducement to the undertaking of the work, if resources can be found for its execution.

The board of public works, therefore, whilst they are persuaded, that nothing in the power of the general assembly can more largely contribute to the increase of the population, wealth and prosperity of Virginia, than the establishment of the commercial communication proposed, confine themselves to their more appropriate province, of inquiring into the practicability of the scheme, and of raising the pecuniary funds necessary for carrying it into execution. To these objects, their attention has been specially devoted; and they are gratified in believing, that the work is not only practicable, but that the necessary resources can be commanded, without relying upon the precarious supplies, afforded by a subscription to a stock, depending for its profit upon contingencies; without calling in the aid of the public treasury in any event; without oppressing, but, on the contrary, greatly benefitting those who will be more immediately affected by the payment of tolls, and probably without any aid from the fund for internal improvement; certainly with the aid of that fund to an extent so limited, as not to impair its capacity, to give due assistance to any other work of public utility which may present itself.

This may be effected by applying the annual resources which may be commanded, (and which will hereafter be stated in detail,) to the payment of interest upon a capital to be employed in the execution of the work, rather than by applying such annual resources to the work itself. It is obvious that those who have the benefit of any work of internal improvement, must pay in the shape of tolls, an interest upon the capital expended on it; and if those who have advanced such capital have taken upon themselves any risk, such risk must also be compensated in tolls, and that liberally. Thus, if it were proposed to raise funds for the proposed work, by a subscription of stock in the usual mode, it would be necessary, in order to induce the individuals to embark their funds, that a fixed and unalterable tariff of tolls should be established, which should afford a reasonable prospect of producing to the stockholders a profit of ten, twelve or fifteen per cent. as a compensation for their risk, real or supposed, as well as for the use of their money: or to ensure some fixed profit, exceeding the rate of legal interest. It is therefore more beneficial to those who will avail themselves of the use of the proposed improvement, that the work shall be effected by a capital borrowed at six per centum per annum; in which case, tolls will only be required to the extent necessary to pay the interest; than by a sale of stock depending for its compensation upon fixed tolls. It is believed that upon the pledge which will be hereafter suggested, money may be borrowed at the rate of six per centum per annum, as fast as it can be expended in the works.

A canal from the basin at Richmond, to Covington, at the mouth of Dunlap's creek; a good graduated road from thence to the fall of the Kenhawa, and the improvement of the navigation of that river, according to the suggestion of the engineers, with a provision for the final completion of the road, when circumstances will permit, are preferred by the board of public works, to any other improvement on an inferior scale, even as it relates to the transportation of the commodities and agricultural products of that part of Virginia naturally and necessarily connected with this line of communication. It appears by the estimates of the principal engineer, submitted to the legislature by the board of public works, in the course of the last winter, that, after allowing for such additional tolls, as the most improved navigation would require for its support, the difference in the whole cost of transportation would be greatly in favour of the most improved system of navigation. To those estimates, the board of public works beg leave to refer. The collateral improvements spoken of in the engineers' reports, ought to be taken up as soon as circumstances will permit.

By the report of the principal engineer, it appears that the whole works contemplated would cost 1,927,069 dollars; and by the report of Mr. Briggs, the additional engineer employed by the board of public works, that they would cost 1,945,446 dollars. The board of public works have the utmost confidence in the judgment and integrity of both of those gentlemen, and they have not the slightest ground to doubt of the verity of the data upon which their estimates are bottomed; on the contrary, they are inclined to think, that their estimates are liberal; since the price of provisions and labour has greatly fallen, and will probably continue low for many years; a circumstance deemed peculiarly favourable to the execution of the work in question, at this time. Yet, in making estimates for a work of great magnitude, it is thought to be prudent to make liberal allowances for unforeseen contingencies. The estimate of Thomas Moore is therefore taken, as the basis of the estimates of the board of public works, with an addition of twenty-five per cent. except as to the road. Upon these principles, the account would stand thus:

For the rivers, - - -	$1,827,099
Add 25 per cent. for unforeseen contingencies, - - - -	456,767
For the road, - - - -	100,000
Total,	$2,383,866

Of this sum it is probable that not more than $120,000 per annum could be advantageously expended. This sum would employ as many labourers as could probably be procored. At that rate the work would be completed, and the whole sum expended in the following manner, to wit: in the first year the Kenhawa navigation would be completed, for the sake of getting immediate possession of the tolls on salt, and other articles transported on that river; and in the first year a part of the James river canal would also be cut; in the second year the James river canal would be completed to Pleasants' island: in the third and fourth years the road would be finished, and at the same time the James river canal would steadily progress to its final completion.

The expenditure of $120,000 per annum would, for the first ten years, (at the expiration of which the canal would be completed to Lynchburg,) require the following provision for the payment of interest, viz:

At the end of the	1st year,	$ 7,200
do.	2d year,	14,400
do.	3d year,	21,600
do.	4th year,	28,800
do.	5th year,	36,000
do.	6th year,	43,200
do.	7th year,	50,400
do.	8th year,	57,600
do.	9th year,	64,800
do.	10th year,	72,000
	Total is	$396,000

How may this sum be provided for the annual payment of interest?

It is understood that the James river canal company are disposed, for the sake of promoting this important object, to come into any terms which shall effect it, whilst the value of their existing rights shall be secured to them. The board of public works have supposed it to be beyond their province to negotiate any terms with the James river company; and if not beyond their province, yet that such a regulation would more properly belong to the general assembly. But upon the presumption that some equitable arrangement may be made with that company, without which no step can be taken towards the contemplated improvement, it is supposed that the income of the company will be applicable to the aid of the works in contemplation, whenever they shall be commenced. The income of that company has gradually increased, and now may be fairly stated at 35,000 dollars per annum, although the annual income fluctuates with the variations of the seasons, insomuch, that the late dry season, has reduced it the last year to 30,185 dollars 24 cents, from 38,820 dollars 51 cents, the amount in 1817, and 37,392 dollars 10 cents, the amount in 1818; as will appear by the annexed document marked (A). The present value of the shares of the company is 375 dollars; rating them at 400 dollars, their whole capital will be worth 280,000 dollars. The annual interest of which is 16,800, which, deducted from the 35,000 dollars, leaves 18,200 dollars, for the collection of tolls, and the expenses of keeping the works in repair; a further deduction of 6,200 dollars per annum ought to be made; leaving 12,000 dollars nett per annum, for the payment of interest.

The tolls upon the Kenhawa, at two cents per bushel on salt, together with tolls on other articles, as proposed in the supplemental report of the last year, would probably amount to 15,000 dollars per annum. But, not to hazard a miscalculation, suppose them to nett 10,000 dollars per annum, which is no more than the toll upon salt; leaving the residue of the tolls to meet the expenses of collection, &c. The coal to pass the canal, anticipated by the engineer, from the information of a gentleman extensively engaged in the coal trade, to promise 2,500,000 bushels per annum, and assumed by the engineer at 2,000,000 bushels per annum, may, to avoid any hazard of miscalculation, be stated at 1,250,000 bushels per annum, which, at a toll of two cents per bushel, would yield 25,000 dollars per annum. Upon these data, the resources for paying the interest for the first ten years would stand thus:

To be raised in ten years, for the payment of interest,		$396,000
To be raised from the present tolls of the James river, 10 years, at 12,000 dollars per annum,	$120,000	
To be raised from the Kenhawa tolls, 9 years, at 10,000 dollars per annum,	90,000	
To be raised from toll upon coal, 8 years, at 25,000 dollars per annum,	200,000	
		410,000
Leaving a surplus of		$14,000

These estimates are considered as safe, since no allowance is made for the increase of the ordinary trade upon the James river, or for the increase of salt and other trade on the Kenhawa, or of the coal trade on the James river, in the course of ten years, all of which are morally certain: and that in respect to salt and coal to an indefinite extent.

Nor is any allowance made for any increase of tolls on the ordinary trade of the James river, before the canal has reached Lynchburg; although the benefit derived from the canal to large and fruitful districts below Lynchburg, and even to the country above, would, in the event of its being necessary, in order to the completion of the work, render it just and proper that additional tolls should be imposed, in proportion as the canal shall progress.

According to the foregoing estimates, there would be expended on the James river, in ten years, from Lynchburg to the mouth of Dunlap's creek, 1,200,000 dollars, which, including the continuing interest on the 1,200,000 dollars, before expended, would require a provision for the payment of interest, according to the following table, viz.

11th year,	79,200
12th year	86,400
13th year,	93,600
14th year,	100,800
15th year,	108,000
16th year,	115,200
17th year,	122,400
18th year,	129,600
19th year,	136,800
20th year,	144,000
	$1,116,000

To provide for the payment of which, the income of the improvements completed in the first ten years may be assumed as follows:

James river tolls, as at present, after deducting the sums necessary to pay interest on the James river stock, and keep the works in repair, at 12,000 dollars per annum,	$120,000
Kenhawa tolls increased by the increased trade on the river, without increasing the rate of tolls, say increase 50 per cent. 15,000 dollars for 10 years,	150,000
To tolls on coal, arising from increased quantity, say 50 per cent. 37,500 dollars per annum for 10 years,	375,500
Additional tolls on James river, less than 150 per	

cent. advance on the present rate of tolls, 50,000 dollars per annum for 10 years,	500,000
	$1,145,500

In examining the foregoing statement, it is proper to observe, that no tolls from the road are brought into the estimate, although some, and probably to a considerable amount, will arise, in the course of the 20 years, and will make a part of the fund for the payment of interest; that no allowance is made for tolls upon articles going up the river, which, in consequence of the facility of navigation, would probably be very great upon articles necessary for the consumption of the neighbouring country and east Tennessee. This resource would be applicable to the payment of interest, and would probably be very considerable. Nor is any allowance made for the natural and steady increase of the downward trade upon the James river, which, judging from past experience, will be great, and afford other funds for the payment of interest, and no more is allowed for the increase of the coal and salt trade in twenty years than 50 per cent. whereas, in all probability, both would be quadrupled. All these considerations being weighed, it seems to be a reasonable conjecture, that the present rate of tolls on James river need never be raised. On the other hand, the present revenue on coal received by the James river company is not taken into the account, because it is inconsiderable, since they only receive toll on the coal boats as on empty boats passing the canal.

Upon the completion of the work, a tariff of tolls should be adjusted on equitable principles, which should insure an income amply sufficient to meet the interest on the capital expended, and all incidental expenses. And as upon any fixed rate of tolls the income would continually increase, the surplus income should be reserved, to be applied as a sinking fund, for the extinguishment of the principal debt.

The consideration that, upon the plan proposed, the whole subject will be continually in the power and under the control of the general assembly, so that they may progress to the completion of the work, or suspend it, as it may be found expedient, affords an additional reason why this plan shall be adopted, rather than that of incorporating a company for the purpose of effecting this improvement.

It is believed that upon a pledge (for the payment of interest) of 2 cents per bushel upon the salt on the Kenhawa, with other tolls on the same river, according to the tariff reported to the general assembly in the supplemental report of the last year; and of 2 cents per bushel on coal on the James river; and from the present James river tolls, after setting apart a sufficient fund thereof to pay the ordinary expenses of collection and repairs, and for compensating the present stockholders; with a power reserved to the legislature to impose additional tolls on the James river, as the works may progress and become useful; and of all the tolls on the road, together with a provision that any deficiency in the payment of the interest, from the funds so pledged, shall be made good out of the income of the fund for internal improvement; the sums necessary for carrying the foregoing plans into execution may, from time to time be borrowed as they may be wanted.

The board of public works do not recommend to the general assembly to provide for making good any deficiency in the funds appropriated for the payment of interest, out of the income of the fund for internal improvement, under the apprehension that any such deficiency will occur; but because they think that such a pledge will give unbounded confidence to those who may be disposed to lend money at 6 per cent. per annum, upon an absolute assurance of the punctual payment of interest, and the security of the principal. And such an additional pledge may be indispensably necessary, because the board of public works are apprised, that those who are not required, by a sense of public duty, to consider minutely the details of the plan of improvement under consideration, are not at all likely to examine into them; and those who do not examine them will probably be alarmed at the magnitude of the subject, and condemn, without consideration the enterprise, as visionary and delusive. Such persons would of course demand an unquestionable security for their money before they would advance it. If, however, contrary to the anticipations of the board of public works, there should be any demand on the fund for internal improvement, by reason of such pledge, provision may be made that they shall be entitled to a six per cent. stock to the amount advanced, but not to receive an interest thereon until the works shall have progressed to such a point as would justify the levying additional tolls for the payment of such interest. This would be in strict conformity with the principles of the act creating the fund for internal improvement, which contemplates in all cases that the board of public works shall receive no dividends on the money advanced by them in aid of any company, until the works shall produce an income sufficient to pay to individuals an interest on the capital advanced by them of six per centum per annum from the time they advanced their money. And surely the aid of the fund for internal improvement, if necessary, should not be withheld from a work in which so great a portion of the people of Virginia are so deeply interested.

In the foregoing review of the subject under consideration, the board of public works have purposely founded their estimates upon the supposition, that the contemplated works will require an expenditure greatly exceeding the estimates of the engineers; and that the annual income from the works will, on an average of twenty years, be less than half of what there is just reason to believe will in fact accrue thereon; because it was thought that if they erred, it was better to err on the safe side. It only remains to observe, that if the income should be found to be equal to the real expectations of the Board of Public Works, there will be no occasion to borrow any money for the execution of the work above Lynchburg; but that the surplus income, after providing for the payment of interest on the money borrowed for completing the work to Lynchburg, and for the payment of the incidental expenses of the collection of tolls and repairs, would be sufficient alone to complete the residue of the work within the time proposed, and thereafter form an active sinking fund, for the speedy extinguishment of the debt

All which is respectfully submitted,

TH. M. RANDOLPH,
President of the Board of Public Works.

BERNARD PEYTON,
Secretary of the Board of Public Works.
Richmond, 24th Jan. 1820.

The annexed table is the document referred to in Mr. Randolph's report, and contains receipts of the James River Company from 1816 to 1819, inclusive.

Receipts on account of the James River Company, for the years

1816.	For tolls	$27,880 61
	rent of water,	3,890 00
	rent of ground	560 00
		$32,330 61
1817.	For tolls	$31,370 51
	rent of water	3,890 00
	rent of ground	560 00
		35,820 51
1818.	For tolls	$32,902 10
	rent of water	3,890 00
	rent of ground	560 00
		37,352 10
1819.	For tolls	$25,735 24
	rent of water,	3,890 00
	rent of ground	560 00
		30,185 24
		$138,688 46

How far the projected canals are capable of beneficial execution or not, we are unprepared to say, but the following report of Mr. Isaac Briggs on the subject, contains so much geographical and statistical knowledge as to justify its insertion in our general view. It was dated at Richmond, January 15th, 1820.

Summary.—1st. Of Distances.

Canals proposed to be made from Lynchburg to opposite the mouth of Cowpasture river	77 m. 11.46 ch.
Navigation on the river in 4 places, by means of towing paths on shore, and in 4 crossings	7 59.64
From Lynchburg to the mouth of Cowpasture, total distance	84 m. 71 ch.
Canals proposed to be made from the mouth of Cowpasture river to the mouth of Dunlap's creek	16 m. 72.79 ch.
Navigation on Jackson's river in 3 places, by means of towing paths on shore, and in 2 crossings	2 m. 7.21 ch.
From the mouth of Cowpasture river to the mouth of Dunlap's creek, and to 11 chains above it, total distance,	19 miles.
Total length of 3d section,	103 miles and 71 chains.

2d. Of Expense.

From Lynchburg to the mouth of Cowpasture river, including dams, guard-gates, aqueducts, and culverts	$280,736
Lockage, 533.45 feet, at $625 per foot	333,406
Road-bridges 13, at $500	6,500
Farm ditto 80, at $200	16,000
	$636,642
For engineers, superintendence, and contingencies, 10 per cent.	63,664
Amount	$700,306
To which add the amount from the mouth of Cowpasture to the mouth of Dunlap's creek,	227,830
This sum is the total amount of expense for the 3d section	$928,136

I now close my estimates by a recapitulation.

I. *Independent Canals.*

	Miles.	Chains.	
1st Section, from the basin to Pleasants' island, distance	24	49.12	
Expense			$159,769
2d Section, from Pleasant's island to Lynchburg, distance	120	55	
Expense			711,891
3d Section, from Lynchburg to the mouth of Dunlap's creek, distance	103	71	
Expense			928,13
Total length of continued independent canals	249	15	
Total expense of ditto			$1,799,766

II. *The main connecting Road,*

As proposed, from the mouth of Dunlap's creek on Jackson's river to the Kenhawa, just below the great falls. Distance	89 68	
Expense		$100,000

III. *The Kenhawa River,*

From the great falls to the Ohio river at Point Pleasant, distance	94 00	
Expense of improvements which will render the navigation good		$45,650
The whole length of the proposed commercial route from Richmond to the Ohio river at Point Pleasant, is	433 miles.	
The whole estimated expense of the improvements contemplated on this route, is		$1,945,446

I will now give a summary of the cost of improving those routes (as far as we have surveyed them) which naturally converge to and intersect the *main line* of commercial communication.

1st. "Of Craig's creek, from its mouth to the highest point" (the mouth of John's creek) "susceptible" economically, "of navigation,"	
The distance is 48 miles and 75 chains.	
The probable expense of making a sluice navigation will be	$6,000
The length of portage, from the mouth of John's creek to the mouth of Sinking creek, on the Kenhawa river, is 43 miles and 43 chains. No part of this distance is susceptible of navigation without an expense, in our judgment, quite inexpedient. As this last mentioned line was surveyed and levelled in the hope of *navigation*, further surveys will be necessary, when it shall be decided to locate a *road*, the expense of making which is therefore not estimated.	
2d. "Of the Kenhawa," commonly called New river, from the mouth of Sinking creek to the mouth of Greenbrier river,	
The distance is 55 miles and 14½ chains.	
The probable expense of making a sluice navigation will be	10,400
3d. Of Greenbrier river, from the mouth of Howard's creek, to Kenhawa river,	
The distance is 49 miles and 72 chains.	
The probable expense of making a sluice navigation	34,525
4th. Of the Kenhawa river, from the mouth of Greenbrier to Bowyer's ferry,	
The distance is 46 miles and 32½ chains.	
The probable expense of making a sluice navigation, with three locks	39,850

5th. Of the Kenhawa river, from Bowyer's ferry to the foot of the great falls, The distance is 20 miles and 60 chains. The probable expense of making a sluice navigation, with *tracking-ways*, made on shore along all difficult and rapid places; the boat is towed by men walking on those paths	18,850
The total estimated cost of all those incidental improvements, is	$109,625

I shall close this Report with a few general remarks. All our levels have been taken with an excellent instrument, and with great care. In all our levelling for the canal, the base line was noted with reference to fixed objects, such as pegs driven firmly into the ground, and frequent bench marks made on trees. Levels had been taken during the preceding year, under the direction of Thomas Moore, with reference to the surface of the water in the rivers, liable to some variations. I had with me Thomas Moore's notes; and from the mouth of Dunlap's creek to Lynchburg, I made, between my levelling and his, frequent comparisons at marks which he had left. The following are the results: The distances mentioned are from the mouth of Dunlap's creek downward, as measured on Jackson's and James rivers. The differences between our levels are reduced to inches and tenths of an inch.

Points of comparison.	Difference of levels.
At 31 miles	1.1 inches.
65	6.7
82	4 0
86	4.4
94	0.5
109	0.1

From Lynchburg to Pleasant's Island, 120 miles and 55 chains, the levelling for the canal, compared at both extremes with the surface of the water, gives the whole fall six feet less than that on the river, in the preceding year. This, on the whole distance, yields an average of not quite six-tenths of an inch per mile. We have no doubt an error has been committed in levelling, either on the river or for the canal: but as the disagreement was not discovered until we had gone over the whole ground, and made the final comparison, we had not time to search for and detect it; and knowing it cannot affect materially the general result of our estimates, we deem it unimportant. Even if the whole amount of error be in levelling for the canal, (which I think is not probable,) its utmost effect would be, by increasing the lockage, to add $4,125 to the aggregate amount of estimates.

Having carried a levelling along Craig's creek, from its mouth to the mouth of John's creek, then across the mountains, and down Sinking creek to its mouth, 92 miles, we left a Bench mark on the bank of Kenhawa. In carrying from the mouth of Dunlap's creek a second levelling, in crossing the mountains the vane was put into a new hand, and before we arrived again at the mouth of Sinking creek, as we passed down Greenbrier and up Kenhawa, I suspected that an error had been committed at a certain place. When we arrived again, by a distance of 133 miles, at, and compared with, the mark at the termination of our former levelling, there was a disagreement. On our return across the mountain, the suspected place was examined, the error was found there, and when this correction was applied to the notes, the difference of levels was but 6.7 inches. This proves the excellence of our instrument.

Finding that we had collected a large mass of materials, and that for a detailed exposition of the whole, many calculations, merely technical, but of considerable labour, would be necessary, it was arranged between the principal engineer and myself, that I should make most of the calculations which were equally essential for both; and that, as this would of course consume much of my time, I should, in my report, respecting *certain parts*, adopt a more general form, and that, in *these parts*, he would be therefore more particular in detail, than perhaps would otherwise have been the case.

I am convinced the subject will not suffer by this arrangement, as I know him to be eminently qualified for the task; and probably more information and more satisfactory views will be laid before you, and much earlier in this way, than would have been possible, had we made every calculation, each for himself, and had each gone into every particular of detail on every point. The improvements proposed on Craig's creek, on the western waters, and the new commercial road, their probable cost and consequences, and every part of the whole subject, as it relates to political economy, and as it is calculated to benefit peculiarly the Commonwealth of Virginia, have been freely discussed between us, and, without any sacrifice of judgment, the uniform results have been, a harmony of views and concurrence in opinion. I therefore conceive, if you approve, that I hazard nothing by reposing in these respects on his report.]

The canal commissioners of the state of New York have, in their report of the year 1812, exhibited calculations of the cost of transportation on an independent canal; the result is *one cent per ton per mile*.

The late lamented Robert Fulton, in a letter to Gouverneur Morris, now also deceased, remarks on those calculations, as follows:

"In the Report of March, 1812, page 9, the commissioners gave calculations on the expense of conveyance by canals, which calculations were drawn from experience acquired on canals in England, as to the quantity of work that two horses and three men could do in eight hours; to which adding the wear and tear of the boat and canal, the decay of horses, and interest on the capital expended in purchasing horses and boats, also the profit on the boat and the wages, which are higher in this country than in England, it is shown that the total expense amounts to no more than *one cent per ton per mile*. As I passed three years at various canals in England, to obtain practical knowledge on the manner of constructing them, and to make myself familiar with their advantages, and was well acquainted with some of the best engineers, *I know this calculation to be correct.*"

I believe that recent experience on the grand canal of New York confirms the estimate.

John E. Howard of Maryland, a gentleman of respectability and extensive information, published, in 1818, a pamphlet, entitled, "Remarks on the intercourse of Baltimore with the Western Country," in which pamphlet the author states, that "one of the proprietors of the line of stages from Baltimore to Wheeling, a gentleman of considerable experience in this way, came to the following proposal, *which*," (the author adds,) "*is hereby offered to the public*," *viz.*—"To contract for the regular carriage of goods from Cumberland to Uniontown, near 60 miles, at the price of 62½ cents per cwt. if the road continues without any repairs, but if there are any measures taken to keep the road in repair, he will then undertake to do it at 50 cents per cwt. provided that he have regular employment and a return load."

The road alluded to in the above mentioned proposal is that part of the national turnpike which crosses all the ridges of the Alleghany mountains. 50 cents per cwt. for 60 miles, gives the rate of $\$16\frac{2}{3}$ per ton per 100 miles, or $16\frac{2}{3}$ cents per mile. It appears then, that land transportation, on a good road, kept in repair, can be effected for $16\frac{2}{3}$ cents per ton per mile; but to be quite safe, we will assume it at 20 cents.

To estimate the expense of transportation on the Kenhawa, let us suppose a boat of 60 tons burden. Surely ten men can navigate such a boat from the falls to Point Pleasant in 4 days, and return to the falls with 30 tons (for there can be no doubt of a return cargo,) in 6 days; allow 2 days to load and discharge: we have then 12 days for the voyage, and 90 tons transported 94 miles by ten men in that time. The wages of ten men for 12 days, at a dollar per day each, gives the amount of \$120. To this add \$10, for ten dollars on every voyage will more than cover wear and tear of the boat, and interest on the capital employed; we then have the cost of transporting, from the falls to Point Pleasant, \$130 for 90 tons 94 miles, equal to $\$1\ 44\frac{4}{9}$ for one ton that distance, and to the rate of 1 cent and not quite $7\frac{1}{13}$ per ton per mile. I will state it at 2 cents.

Now let us apply these rates to the transportation of a ton of merchandise from Richmond to Point Pleasant:

From Richmond to the mouth of Dunlap's creek, by an independent canal 249 miles, at one cent	\$2 49
From the mouth of Dunlap's creek to the great falls of Kenhawa, by the proposed new road, 90 miles, at 20 cents	18 00
From the great falls to Point Pleasant, by the Kenhawa river, 94 miles, at 2 cents	1 88
The whole cost of transportation of a ton of merchandise, taken from Richmond and delivered at Point Pleasant, would be	\$22 37

If this expense were, without making any allowances, calculated *strictly*, on what I believe to be sound data, the amount would be but 18 dollars, $93\frac{1}{2}$ cents.

It appears from very good authority that, besides what has been carried from New York and Baltimore for the supply of the western country, there has passed from Philadelphia to Pittsburg, the whole way (more than 300 miles,) by waggons, the annual amount of more than 4,500 tons of merchandise, at an expense of transportation exceeding \$80 per ton. Baltimore hopes, and perhaps reasonably expects, to be able to transport goods to Wheeling for an expense of \$50 per ton. Surely then Richmond, without being chargeable with expectations too sanguine, may calculate on delivering at Point Pleasant 5,000 tons, if she can do it for \$25 per ton. The preceding calculation makes it but \$22 37. If then we draw from this transportation, a revenue equal to \$2 65 per ton, the *whole expense* on goods sent from Richmond to Point Pleasant will not exceed \$25 per ton; and at the rate of \$2 63 per ton on 5000 tons, it will yield annually \$13,150. This sum would be raised by a toll of one cent per ton per mile, from Richmond to the mouth of Dunlap's creek, and 14 cents per ton for the whole distance from the falls to Point Pleasant, leaving the returning trade on Kenhawa, and that on the road both ways, entirely free from charges on account of revenue.

The preceding statement is made with respect to the outward trade only. There can be no doubt the return trade would be quite equal to it, making the revenue equal to \$2 63 per ton on 10,000 tons, or the annual amount of 26,300 dollars.

It will be obvious, I think, on the slightest investigation, that this is a very moderate estimate. It is certainly far short of what would be the reality, if goods can be delivered at Point Pleasant at no greater expense for conveyance than \$25 per ton. I have stated, that 4,500 tons are carried annually from Philadelphia to Pittsburg, at an expense exceeding \$80 per ton; I ought to have said \$140 per ton, for this is rather below the fact at present. The *hope* of her merchants is to reduce it to \$10 as the minimum—and Baltimore *hopes* to reduce to \$50 her freight to Wheeling. I even admit their hopes to be realized. Then, if Point Pleasant be as favourably situated for extensive distribution as Pittsburg or Wheeling, (and I think this cannot admit of a doubt,) and Richmond can deliver goods there for \$25 per ton, what will be the inevitable consequences? Articles of great value in proportion to their weight will bear a high rate of transportation, but a vast amount of articles of more weight in proportion to the their value will be excluded. A great many kinds of goods, prohibited at \$140, can be carried at \$80; many prohibited at \$80, can be carried at \$50; and still more prohibited at \$50, can be carried at \$25. This consideration, even at the rate of tolls, which I have purposely assumed *very low*, would vastly augment the final result beyond my estimated revenue of \$26,300, but even this sum affords an animating prospect.

I am fully convinced that, to accomplish all the improvements proposed, nothing more will be necessary than to issue at 6 per cent. stock irredeemable for a limited time, and perhaps thereafter only in a limited proportion, pledging for the annual, or half-yearly payment of interest, the James river tolls; those at present existing for a commencement: and, as the work advances, and more funds become necessary to carry it on, the proceeds of canal tolls will be a continually augmenting resource for pledges for additional stock. When an independent canal shall be made as far as the mouth of Dunlap's creek, the before mentioned fund of \$26,300 may come into operation; this, in additton to that arising from the trade of James river, will unquestionably form a fund sufficient for further internal improvements, even beyond our present views, for redeeming, if thought expedient, the stock previously issued, and for diminishing the rate of tolls.

It has been already stated, that we have explored the Kenhawa, or New river, no higher than the mouth of Sinking creek: but every information I have been able to obtain of that noble river seems to invite strongly an examination of it, perhaps even as far as the southern boundary of Virginia, and especially respecting the practicability of a connexion with the Holstein river. A very valuable trade may be expected on the upper parts of Kenhawa river; and if the connexion alluded to be found practicable, at a reasonable expense, the trade may be extended to the state of Tennessee—it may descend the Kenhawa, ascend Greenbrier to the mouth of Howard's creek, and then, by a portage of but very little more than 26 miles, it may enter the James river canal at Covington. This portage may, at an expense which may *hereafter* be found expedient, be diminished to 15 miles, by making a navigation on part of Dunlap's and on part of Howard's creeks. The upper part of Jackson's river, and the upper part of Greenbrier, will pour their treasures into the same channel.

The consequences of these improvements will be, vast quantities of fertile land, now a neglected wilderness, will be brought into cultivation; much already occupied, will be better managed; many useful articles, now untouched, will be produced, and in increasing quantities, because they will bear the cost of transportation, and still leave profit to reward the labour of the husbandman. Geology and chemistry will unlock the now hidden treasures of the mountains. Wherever sulphur, iron, limestone, and slate abound, as they do about the Alleghany ridges, we may, with great reason, expect to find three very useful minerals, gypsum, copperas, and alum. Sulphur is the basis of an acid, which, combined with lime, forms gypsum or plaster of paris; combined with iron, it forms copperas; and combined with alumine (which is the basis of slate) and some potash, it forms alum. Nature furnishes, on a large scale, those useful combinations, and we may add to the list, nitre; but iron, limestone, slate, and sulphur, are extensively useful also in their primitive or elementary forms. All these substances, primitive and combined, are in a vast extent necessary to the arts, and are therefore essential to the prosperity and comforts of civilized society. If the expense of distributing those ponderous materials where they are wanted, instead of leaving a reward to, should be a tax upon labour, those inexhaustible treasures will lie idle in their beds. They will not even be sought for, except as curiosities by the mere man of science, and if found, they will be useless, because confined to the spot.

Nature has been bountiful to Virginia by the location of her fine rivers; yet it is uniformly the wise economy of nature, to leave something to exercise the ingenuity and industry of man. If Virginia neglect to use the means of improving her advantages, so largely offered to her acceptance, she must consent to hold an inferior rank among her sisters.

The state of New York, by her noble enterprises, by her enlightened zeal in developing and applying to internal improvements her own resources, is rising in splendour like a star of the first magnitude in the federal constellation.

The cities of Philadelphia and Baltimore are struggling in earnest competition for the western trade. If Richmond do not rise in the scale of cities to a rank second only to that of the city of New-York, and if the Commonwealth do not still maintain a pre-eminent station among the states, it will not be because nature has denied the means.

Virginia will generously rejoice in the prosperity of her sister states; she will applaud their honourable efforts, and wish success to their enterprises; but at the same time she will be wise enough to improve her own resources, and to use those means which her position gives her, so as to secure to herself her appropriate rank in the nation.

Mr. Briggs, in another communication to the board of works, through Mr. Peyton, its secretary, has given the general levels of the sources of Craig's creek, that branch of James river which interlocks with Sinking creek branch of Kenhawa, in the great valley south-west of the Blue ridge. These elements are of the utmost consequence in forming a correct idea of the country over which canals are designed to be drawn, to unite James and Kenhawa rivers. The following short geographical description will serve to inform the reader of the locality of the two creeks so particularly noticed in the annexed table.

Craig's creek is formed by two branches, John's creek and Craig's creek proper, both rising in Giles county, in Virginia, at North Lat. 37° 20′, and 3° 30′ West Lon. from Washington City. Both branches flow north-east into Botetourt county, in which they unite, and fall into James river, about 15 miles below the junction of Jackson's and Cowpasture rivers, after a comparative course of 40 miles.

Sinking creek rises between Pond and Walker's mountains, and between John's and Craig's creeks, in Giles county, flows south-west 25 miles, and falls into Great Kenhawa, at North Lat. 37° 17′, and West Lon. 3° 42′ from Washington City.

	Miles.	Perches.	Above tide, feet.
James river at the mouth of Craig's creek			925
To the mouth of John's creek, following the bends of the water course	48	300	1270
Highest spring tributary to Craig's creek	8	266	2498
To the lowest point on the dividing ridge	0	116	2551
To the nearest stream tributary to Sinking creek	0	98	2509
To the mouth of Sinking creek	34	51	1585
Following James river up to the mouth of Jackson's river, and thence to the mouth of Dunlap's creek, dividing Bath from Botetourt county, the point of junction between Jackson's river and Dunlap's creek was found to be			1233
Thence to the lowest point on the dividing ridge	16	69	2473
To the mouth of Howard's creek into Greenbriar river, near Lewisburg, in Greenbriar county	12	00	1640
From the mouth of Sinking creek to that of Greenbriar river, is 55 miles, and from the mouth of Howard's creek to that of Greenbriar river, 50 miles. Elevation of mouth of Greenbriar			1333
To Bowyer's Ferry,	46	130	930
Kenhawa at the foot of the Great Falls	20	240	589
Ohio river at the mouth of Kenhawa	94	000	481

The reader, from a comparison of the relative elevations of any route hitherto rendered navigable by canals, can easily determine the probability of effecting such an object, by either of the above routes, through the Appalachian ridges. One observation must be made, that as far as the sources of James river, the table land of the Appalachian chain rises gradually from the Mohawk valley.

Dismal Swamp Canal.

This channel of inland navigation, called the Chesapeake and Albemarle canal, has been dug, to unite those two great sheets of water, and though but partially executed, is of great value in opening markets for the fine timber of the Dismal swamp. It is partly in Virginia and partly in North Carolina.

Santee and Cooper river Canal.

This canal is 22 miles in length, uniting Santee river to the head of Cooper river. The ground rises by an ascent of 35 feet to the summit level, by 4 locks. Towards Cooper river the descent is 68 feet, which is overcome by 9 locks. The locks are formed of brick and stone, 60 feet long, by 10 feet wide. The top water line of the canal is 35 feet, and the bottom 20 feet, with 4 feet in depth. Boats of 20 tons are navigated on this canal. The expense of construction amounted to 650,667 dollars, and the tolls to about 13,000 dollars annually.

Some other canal improvements have been projected and partially executed in South Carolina, but to no very great extent.

Canals Carondelet, Marigny, Lafourche, and Plaquemine, in Louisiana.

From South Carolina to Louisiana no canals have been executed, and few even designed. The canal Carondelet extends from Bayou St. John 1½ miles, to a basin in the rear of the city of New-Orleans. This canal is about 30 feet wide, with 4 feet in depth, without locks; through it the tide flows into the basin.

The Lafourche canal is cut from that river 16 miles below its efflux from the Mississippi. It is opened from the right bank into a small creek uniting with lake Verret. It is through this channel, at high water, that boats are taken to and from the lower part of Attaceapas into the Mississippi, or from the latter stream.

Plaquemine canal is cut from the Mississippi river into Bayou Plaquemine, at its efflux from the Mississippi. The mouth of the Plaquemine is closed by a raft of timber, and the canal, a short cut of about 400 yards, was made across the point below the Bayou.

The two canals of Lafourche and Plaquemine are of about equal dimensions, that of Lafourche is, however, rather larger than that of Plaquemine; both are too shallow, and only navigable in times of high flood.

Canal Marigny is designed also, like that of Carondelet, to unite Bayou St. John to the Mississippi, but remains unfinished. The plan was, to leave the river immediately below Fort St. Charles, in New-Orleans, and extend through the intermediate plains, so as to enter Bayou St. John some distance below the Fauxbourg St. John.

Though this article has been extended to great length, much still remains to complete an entire view of the inland navigation of the United States. In the article Mississippi, and this, expressly on the subject, we trust a very ample mass of matter has been for the time condensed into one view. That any material point has been omitted we are unaware.

If correct documents could have been procured, a particular notice would have been taken of the contemplated canals around the falls of Ohio, but that not being the case, any view we could have taken would have been too general to have been satisfactory; and a similar observation applies to some other points, of less importance, it is true, but sufficiently so to deserve some attention in a general survey.

OF THE MEANS EMPLOYED TO FACILITATE INLAND NAVIGATION.

I. *River Navigation.*

As the inland navigation of all countries commences by those channels which nature has provided for the discharge of superfluous waters of the interior, our attention will be first directed to those circumstances in which the navigation of rivers differs from that of the open sea.

In many rivers, the vessels which are constructed for the sea are enabled to ascend to great distances, without the necessity of any modification, either of their own shape, or that of the river. But, as we proceed, the river becomes obstructed by shallows; its channel, narrow and winding, often completely interrupted by rapids, and even cataracts or falls; the quantity of water diminishes too much, or is in excess. In some rivers the difficulties commence by bars at the very mouth, and in all of them the descending current forms a continual obstacle to the upper trade.

But the river navigation has also its advantages; for, being free from the storms and waves of the ocean, the vessels intended for them alone do not require the strength and convex-shaped bottom of sea vessels, but are built flat, and of great length and breadth, in proportion to their depth, so that they may carry large cargoes, and a great surface of sail, with little draft of water. In tide rivers there is a current alternately upward and downward, so that nothing more is required than to anchor the vessel until the current is about to proceed in the intended direction. In many rivers where there is no tide, as in the Nile, a regular trade wind, blowing contrary to the current, affords the same aid. In the Mississippi similar advantages are obtained by means of the eddies, or counter currents, which are formed behind projecting points of the banks. Where none of these advantages exist, favourable winds must be waited for, or other means resorted to.

Of Bars at Mouths of Rivers.

Bars are the first sort of difficulty commonly met with in entering on the navigation of a river. They almost uniformly occur at the influx of the collateral branch into the main stream, or of the river itself into the sea. The diminished velocity of the stream in these places permits the river to deposit much of the solid matter which it has transported. The river spreads itself over the shoal, and ceases to have any determined channel. The shoal increases in extent and height, until the depth of water becomes every where too small for navigation. Piers or jetties, to confine the bed, are usually resorted to, but, in general, they have only the effect of prolonging the formation of the bar further from the shore. Where the influence of the stream can be made to expand itself into a large pool previous to the influx, in which its silt may be deposited, the port at its mouth may often be preserved by the efflux of clarified waters; but still there will exist the same difficulty of bringing the sea vessel into the river navigation, since the bars will now be formed within the haven. Dantzic, Memel, Venice, the Texel, &c. are ports of this sort, and afford a safe intermediate station for the transfer of goods to the deep sea vessel, from those fitted for passing the shoals to the interior. In other cases, where the embouchure is gradual, and the mouth gently expanding as through the medium of a firth, the change of velocity is in no place so sudden as to give opportunity to the formation of a bar. Thus the river Forth has no bar, nor the Thames, although it has many banks; and such ports only can decay from the gradual filling up of the valley from its head. But, lastly, where the river, like the Tyne, the Dee at Aberdeen, or the Rhone, falls at once into the sea, and almost perpendicularly to the coast, the formation of a bar is inevitable; and as there is, in such cases, a littoral current, either from the tide or prevalent winds, the mouth of the channel or port has necessarily a tendency to the same direction, and removes itself. A deposition takes place between these two currents, and, perhaps, in time, rises into a tongue of sand or gravel, enclosing an interior haven or lagune. Many instances occur of this transition, and it is frequently impossible to prevent it. The only remedy hitherto thought of, is to have a canal from the river above the bar, to some point on the coast, free from the deposits of the river. Of this kind, amongst the ancients, were the canal of Alexandria, in Egypt; of Lone and Arles, at the Rhone; and of Fiumicino, at the Tiber. If the examples be fewer on the coast of the ocean, it is because the tide, while it affords for a longer time the means of crossing such bars, affords, also, by its flux and reflux, a means of removing them. If the above mentioned canals are allowed to run freely, they become merely another mouth for the river, and the evils they were intended to remedy, again take place at the point of their discharge, so much the quicker, also, since they usually pass with greater velocity over new ground, which affords more abundant matter for deposition.

Where bars exist in a navigation river, it is generally owing to the enlarged width of the channel, the natural remedy of which is to contract it, by which means the bottom will be corroded, and create more depth of water; or the height of water will be increased, until a sufficient velocity be communicated to discharge the former quantity of water through the contracted channel; and it is evident, where the bottom is not liable to be corroded, that, if an excavation can be made through it by art, and the width contracted, the great velocity obtained will keep it open; but, if an excavation is made without this precaution, it will become a trap for the depositions. Contractions of this sort may be made by a single dyke or jetty projecting across the greater bed of the river, and, to prevent mischief, should not be made higher than necessary for the navigation, so that all higher floods may pass over it; but, as the velocity occasioned by such a jetty, will not continue far down, shoals will again begin to form below it, and a similar obstruction must again be had recourse to, and so on until the depth of the channel requires no amendment. Improvements of this kind have been effected on the Chester, Dee, and the Trent, in England; the river Clyde, in Scotland, the Boyne, in Ireland, and the harbour of the New Diep, in North Holland. For an account of the effect of corrosion, or the increased velocity produced by obstructions to the current, see our article Bridge, where tables are given.

Of the Manner of Propelling Vessels.

In the lower parts of rivers, where there is sufficient room, deep water, and not too strong a current, vessels are navigated by the sail and oar, but, proceeding upwards, poling or setting along the bottom, or tracking along the banks, are the means employed. Through short rapids, warping by mechanical power, applied by a cable, if often useful; but when the current becomes excessive, or the depth of water too small, artificial means of navigation have been invented, by which the ascent is overcome, and the voyage continued on successive kinds of still water.

In rigging vessels for navigating rivers by the sail, much depends on local circumstances, or the customs of the country. On the Thames, and most English rivers, the barges are fitted with a falling mast, to pass under bridges, on which are mounted fore and aft sails, like those of a sloop. They usually pass singly. On the Loire, boats go in fleets of 6 and 8, the largest first. Those about 90 or 100 feet long, 11 to 14 feet wide, carry masts of 70 or 80 feet, the next less, and so on, diminishing to the last. On these masts are mounted lofty square sails. On the lower Rhine, the Cologne ships are perhaps the largest used in inland navigation, being frequently of 1000 tons burden. They are fitted with three lofty masts and top masts, like sea vessels, and draw only five feet water. On the Nile, the canja has a short mast, with an immense triangular or latteen sail, the yard of which, according to Bruce, is sometimes 200 feet long. These large sails, which the still water of inland navigation permits to be used with safety, are a cheap and powerful means of impulse, but, as the rapidity increases, it follows that, independent of the depth of water, there is a term arising from the slope only, at which navigation by the sail must cease, the action of the wind upon the sails being balanced by that of the water at the prow. It has been found by experience, that this term occurs a little above the place where the current ceases to carry gravel; or, in our chief European rivers, where the slope becomes about one in 2000, or about 2½ feet in a mile. Accordingly the rivers of which the bottoms are composed of materials finer than gravel, viz. sand, mud, ooze, &c. are capable of being navigated by the sail, provided they have depth of water, and are not crooked.

Mathematical writers have endeavoured to reduce the action of vessels propelled by sails to calculation, so that the limit above mentioned might also be determined by an equation depending on the velocity of the wind and river, the magnitude of the sails and prows. Such an inquiry would, however, be of little value for that purpose, since, in most rivers, the numerous craft employed, have long ago determined this limit by experiment. But it will be of considerable importance to inquire what are the actual relations between the various means of impulse, and what are the real velocities which each of them may be expected to communicate to vessels employed in navigation. It would lead us into far too wide a digression from our present subject, to give this matter all the consideration it merits. At present, we shall confine ourselves to those parts where the common laws of hydrostatics, as far as yet regulated by experiments, seem applicable to the simple case of direct motion of vessels, leaving the more intricate problems of windward, leeway, &c. for the article Seamanship.

According to the common theory of the impulse of fluids, it is assumed, that each particle of the fluid in motion will strike a solid body in its path in the same manner, and with the same force, as in the collision of hard bodies in free space; therefore, since the number of particles striking in a given time will be as the velocity, and the force of each particle also proportional to the velocity, we have, as a first principle,

1. The resistance or impulse is as the square of the velocity.

2. The number of particles, and, consequently, the resistance, will be as the density of the fluid, and the magnitude of the surface.

Again, in oblique impulses. Let AB (Plate CCCCVIII. Fig. 1.) be the place exposed to direct impulse in fA, fB; BC, the same plane, exposed obliquely to the same fluid. The number of particles intercepted by BC, will be only as DB or CE, that is, as the sine of the angle of incidence O *o* B; but also the perpendicular action of each particle *o*, as *o m*, will be diminished in the proportion of $o\ m : o\ n = \text{BC} : \text{CE}$, that is also as the sine of incidene; so that, as a third principle, we have the direct impulse, or resistance, to the oblique perpendicular impulse, as the square of radius to the square of the sine of the angle of incidence. From these principles it has been deduced, that Cor. I. the impulse on a cylinder, or the level surface of a cylinder, is two-thirds of the direct impulse on its transverse section through the axis; Cor. II. the impulse on a sphere is half that of its great circle.

In like manner, from the same principle, it has been deduced, that the resistance or direct impulse of an unelastic fluid on any plane surface is equal to the weight of a column of the fluid having the surface for its base, and a height equal to twice the fall required for producing the velocity of the motion through the fluid. In elastic fluids, the impulse is double of the above. (*Principia*, ii. p. 35. 38.)

Though this subject has exercised the ingenuity of the greatest mathematicians of Europe, it does not appear that the theory of resistance here given, from the investigations of Newton, is at all conformable to experiments; but, since we have as yet no better to direct our researches, we may at present adhere to this, modifying it only so far as the numerous experiments which have been made on the subject may require. We have already shown (see Bridge) that the action of a fluid on any solid body can, by no means, be considered as that of a number of hard particles striking the body, and recoiling in free space; the fact is, the mobility of the fluid, and the liberty it possesses of rising above the general level, if like water, or of being compressed, if like air, give it all the properties of an elastic body; makes its action on the solid that of a simple pressure, the amount of which may be readily measured by that accumulation. This accumulation becomes, in its turn, a moving power, which impels the parts of the fluid below it to escape in all directions, and, of course, communicates a motion transverse to the general direction of the stream, or rather, perhaps, along the surface of the solid, and with an increased velocity. The figures of that surface, and its adaptation to the natural path, followed by the filaments of water in passing round, and closing in behind the body, greatly affect the observed resistance.

Now let us examine how far the above principles agree with the resistances actually observed. It is very consonant to experiment, that the resistance increases as the square of the velocity, little deviation appears in the smaller velocities, and Newton has shown, that, subtracting a certain uniform quantity for the adhesion of the fluid, the remainder agreed exactly with the theory; and in that of the greater velocities there is a deviation, arising from the inertia of the fluid which accumulates in front, and is rarefied or depressed behind the body.

Whenever a body is moved through a fluid, such as water, a force is required to overcome the resistance thereof. The same, or a similar force, is required to retain a body at rest, which floats in a fluid in motion; in either case the fluid heaps up or accumulates in front of the floating body, until the increasing pressure, in all directions, produced by this accumulation, is sufficient to remove sideways that portion of the fluid intercepted by the floating body, and which afterwards falls into the general current. The effect of this accumulation on the prow of the vessel has, by writers on this subject, been called the *plus pressure*. Again, the fluid, after passing, will require some time and force to fall in towards the after part, or stem of the floating body; this deflection is also caused by some force or hydrostatic pressure, viz. by the water at the stem being somewhat below the level of the passing stream. A portion of the stem, therefore, is not pressed upon by the same force as the bow, even reckoned from the general level of the stream, and independently of the accumulation at the bow; and, therefore, this depression increases the power or resistance of the fluid, by a quantity which has been called the *minus pressure*, or stem resistance. Lastly, the fluid, in passing along the side of the floating body, is subjected to a certain degree of adhesion or friction, which increases with the extent of surface.

2. The resistance is nearly as the square, but apparently increases a little faster. According to Borda's experiments, the resistance to the surface of

		Ratio of Theory to experimemt.
3^2 or 9 inches, being -	9	
4^2 or 16 do. was - -	17.535	1.096
6^2 or 36 do. do. - -	42.730	1.168
9^2 or 81 do. do. - -	104.737	1.294

In larger surfaces, the deviation is probably much greater, as the smaller affords greater facility of escape. The only two fluids of different densities we have to do with, being air and water, we may restrict our inquiry into the actual resistance to them alone. The resistance of a square foot of air, moving with the velocity of one foot per second, appears from the experiments of Mr. Robins,

On 16 inches to be -	.001596 lbs.
Borda 16 inches - -	.001757
Do. 81 do. - -	.002042

With respect to water, Bouguer has calculated that the impulse of sea water one foot per second is 23 oz. on a square foot French measure, and that of wind is the same when blowing 24 feet per second, the density of air would rather give us $\sqrt{900} = 30$ feet. The experiments of the French Academy make the resistance to a square foot moving 2.56 feet per second, to be 7.625 lb. or in English measures, 1.136 square foot moving 2.7263 feet per second, gives a resistance 8.234 lb. avoirdupois, which is nearly the weight of a column of water of this base, having its height equal to the fall necessary for communicating this velocity, and only the half of the resistance assigned by the Newtonian theory. If we calculate from the last number, the impulse on one square foot moving one foot per second, we have 0.973 lb. avoirdupois. A good deal, however, depends on the form and situation of the adjoining parts. The experiments of the Academy were made on a prism or box of two feet square, and four feet long. The resistance on a thin board of the size of the end of this box would have been greater. Thus, according to Buat, the resistance on a square foot wholly immersed in a stream was,

A square foot as a thin plate -	=1.81 lb.
Do. as the front of a box one foot long,	=1.42
Do. as do. three feet long,	=1.29

Sea water about $\frac{1}{25}$ greater.

The resistance to sailing vessels is therefore considerably less in the direction of their length than in that of their breadth upon equal portions of surface, while the resistance to their surface of a sail or an oar is the greatest possible. Both these properties are favourable.

We shall, therefore, assume in our investigation, that the resistance of water in sailing vessels is about $1\frac{1}{2}$ lb. per square foot, moving with a velocity of one foot per second, and that the impulse on a sail is .002 lb. or $\frac{1}{500}$ lb. for the same surface and velocity; proportions not very distant from that of their relative densities, when modified as above mentioned.

Or, if we calculate the resistance for a velocity of one nautic mile per hour, we have air per square foot .005 lb. water per square foot 4.17 lb. being nearly the rates assigned by Mr. Rouse.

But we seldom make the bows of our vessels square, and most frequently place our sails obliquely. Theory here appears to differ widely from experiments. The best experiments hitherto made in this department of our subject are those of the French Academy.

A box of three feet square and 4 long was made and fitted with prows of a wedge-like form, the angles of which varied by 12° in each set of experiments from 12° to 180°, so that the angles of incidence varied 6° from each other. These boxes being immersed two feet in a large basin of water, were drawn obliquely by a line and weights, the motion after a little time becoming very uniform. The time of passing over 96 French feet was then carefully noted, and the resistance calculated from the weight employed, after deducting a certain quantity for friction and the accumulation of water on the anterior surface. The following Table exhibits the result of these experiments. Where col. 1st, Is the angle of the prow; col. 2d, The angle of incidence; col. 3d, The observed resistance; col. 4th, The resistance calculated from No. 1, as the squares of the sines of incidence; col. 5th, The same reduced as the sines of incidence only.

Angle at Prow.	Angle of Incidence.	Impulse observed.	Square of Sine.	Sine only.
Feet.	90°	1000	1000	1000
168	84	989	989	995
156	78	958	957	978
144	72	908	905	951
132	66	845	835	914
120	60	771	750	866
108	54	693	655	809
96	48	615	552	743
84	42	543	448	669
72	36	480	346	587
60	30	440	250	500
48	24	424	165	407
36	18	414	96	309
24	12	406	43	208
12	6	400	11	105
1	2	3	4	5

The error of the theory is as important in the action on sails; for the experiments of Borda and Robins on the oblique impulse of air are very conformable to those of the academicians on water; and the neat experiments of the Society for Naval Architecture exhibit similar results. We may, therefore, observe, that the oblique impulse of the wind is much more efficacious in preserving the ship in the direction of the course than they would suppose; and, in the same manner, the oblique action of the water is more efficacious in resisting leeway.

From the experiments of the Society for the Improvement of Naval Architecture, it would appear that in the ordinary velocities the total resistance of sharp-ended vessels is little more than one-third of those with square ends. The impulsion of the wind, therefore, being at the same time more, we are justified at least in calculating for velocities of five miles per hour or upwards, in assuming a pressure of only $\frac{1}{2}$ lb. per square foot of the cross section the of vessel for one foot per second.

Power of Sails.

From these data, we may now proceed to calculate the rate at which a vessel may pass through the water, her own dimensions, and those of her sails being given.

CASE I. *The Ship sailing before the Wind.*

Take b the breadth, d the draft of water, a the area of the sail, p = the pressure of the wind at one foot per second, q the pressure of water at ditto in one square foot; then w being the velocity of the wind, v of the ship through the water.

As the ship is sailing before the wind we have $w-v$, the velocity of wind in the sails, $(w-v)^2\, p\, a$ the impulse of the wind on the sails, $b\, d\, q\, v^2$ that of the water on the ship; and by equating these, as will be the case when the vessel has acquired uniform motion,

$$(w-v)^2\, p\, a = b\, d\, q\, v^2\text{; and } (w-v)^2 = \frac{b\, d\, q}{a\, p} v^2.$$

Whence $w = v + v\sqrt{\frac{b\, d\, q}{a\, p}} = \left(1+\sqrt{\frac{b\, d\, q}{a\, p}}\right)v$, the wind required;

or $v = \dfrac{w}{1+\sqrt{\frac{b\, d\, q}{a\, p}}}$ the rate of sailing.

EXAMPLE. A vessel of 12 feet beam, and 40 inches draft, is used on the Loire, carrying a sail of 20 yards high, and 9 yards wide.

Here $b\, d = 40$, $a = 1620$, $q = \frac{1}{2}$, and $p = .002$; then

$$\frac{q}{p} = \frac{1}{.004}\text{, and } \sqrt{\frac{b\, d\, q}{a\, p}} = \sqrt{\frac{40}{1620 \times .004}} = \frac{1}{1{\cdot}273}.$$

Wherefore $w = \left(1+\frac{1}{1.273}\right)v = \frac{2{\cdot}273}{1{\cdot}263}v = 1{\cdot}8\ v$ nearly;

that is to say, the wind must be $1.\frac{8}{10}$, or nearly twice the velocity of the ship; so that with a brisk gale of 18 miles an hour this vessel might pass through the water at the rate of 10 miles, and would ascend the river at all times when the current was less than that velocity. Considerable deduction must, however, be made from such calculation. The resistance is taken at the smallest possible, both by supposing the shape of the vessel to be most favourable, and the fluid pervaded to be perfectly free. When the latter is confined in space, as in the bed of canals, or near the side of shallow rivers, the resistance is at least doubled. Taking then 9 at its first determination, viz. $1\frac{1}{2}$ lb. we would find

$$\sqrt{\frac{b\, d\, q}{a\, p}} = \sqrt{\frac{40 \times 1\frac{1}{2}}{1620 + .002}} = \sqrt{\frac{1}{.52}} = \frac{1}{{\cdot}721}$$

and the value of $w = \frac{1 \cdot 72}{\cdot 72} = 2 \cdot 4$ nearly; that is to say, the wind must be $2\frac{1}{2}$ times the velocity of a square-ended vessel in open water; and with a gale of 18 miles an hour, the vessel would make way at the rate of 7 miles.

In a confined channel, according to the experiments of Bossut, the resistance 9 is as high as $2\frac{1}{3}$ lb. at which rate we have $\sqrt{\frac{b\,d\,q}{a\,p}} = \sqrt{\frac{40 \times 2\frac{1}{3}}{1620 \times \cdot 002}} = \sqrt{\frac{1}{\cdot 347}} = 1\frac{2}{3}$ nearly; and $w = 2.7\,v$, or the wind must be $2\frac{7}{10}$ times the velocity of the vessel in a confined channel; so that with a gale of 18 miles the vessel would make way at the rate of $6\frac{2}{3}$ miles.

It is in few rivers, however, that sails of this magnitude can be carried.

CASE II.

As to the motion of a vessel in a side wind, the problem is somewhat more complicated. At present we can only view it in the simplest form, reserving the farther detail to the article SEAMANSHIP.

Suppose AB (Plate CCCCVIII. fig. 2.) the ship's keel, C the centre of the mast, DH the yard trimmed square, WC the direction and velocity of the wind, and CE the velocity of the ship. Thus relatively to the ship the direction of the wind on the sail will be in the diagonal yC, and Cf will be the direction of her vane when in motion, though Cg will be its direction when at rest. This apparent change or heading of the wind when a ship is in motion, is familiar to seamen. Now since the wind yC acts obliquely on the sail DH, we must reduce its direct impulse in the ratio of the square of the sine of obliquity; or draw HK parallel to yC, the perpendicular DK represents the number of particles intercepted by the sail's surface HD; and their perpendicular action on the sail, by drawing the perpendicular LL, will be represented by DL. The other portion of that force acting parallel to the face of the sail, and perpendicular to the keel, can have no effect on the progressive motion of the ship, except in so far as its friction, or the bagging of the sail, may tend to carry the ship to leeward; a force which we do not at present consider, looking on the surface of the sail merely as a plane. Draw the perpendicular yG, then CG is the sine of obliquity yCH, and the impression yC is as the square of CG

Now adopting the former notation, we have $\mathrm{CE} = v$, $\mathrm{WC} = w$, $\mathrm{EG} = w$, sine GyE = sine WCH, and $\mathrm{CG} = \mathrm{EG} - \mathrm{EC} = w\,(\text{sine WCH} - v)$, and since the impulse will be $= a\,p\,(w \text{ sine WCH} - v)^2$, where a is the area of the sail, and p the impulse on a square foot as before.

Now equating as before,

$$a\,p\,(w \sin.\ \mathrm{WCH} - v)^2 = b\,d\,q\,v^2,$$

$$\text{and } w \sin.\ \mathrm{WCH} = \left(1 + \sqrt{\frac{b\,d\,q}{a\,p}}\right) v,$$

$$\text{Where } w = \frac{1 + \sqrt{\frac{p\,d\,q}{a\,p}}}{\sin.\ \mathrm{WCH}} \times v,$$

$$\text{or } v = \frac{w \sin.\ \mathrm{WCH}}{1 + \sqrt{\frac{b\,d\,q}{a\,p}}},$$

which is precisely the former result reduced by the sine of obliquity of the wind.

EXAMPLE. Suppose the wind is 30° behind the beam, or WCH = 30°, then, since the sine of 30° is $\frac{1}{2}$, we have in the former example the velocities of the ship half of those with a fair wind, viz. in the first supposition = 5 miles, in the second $3\frac{1}{2}$ miles, with a brisk gale of 18 miles per hour.

In either of these cases, it may be perceived that the co-efficient of v being constant, w and v are proportional to each other, that is, the velocity of the ship with the same sail is proportional to the velocity of the wind. But $b\,d$ expressing the area of the sail, being under the radical sign, the velocity of the ship, the wind being equal, will be only as the square root of the area of the sail, so that to procure a double velocity four times the sail is required.

CASE III.

But it is not usual to keep the vessel with the yards square when the wind is oblique to the course; a considerable portion of the wind that might be intercepted would be lost, and, if the wind were before the beam, the sail would be taken aback. Besides, ships exposing more surface of sail when their sides are to the wind, are enabled to make up for the loss of power occasioned by the obliquity of action.

Let the sail DH, (Plate CCCCVIII. Fig. 3.) of the ship AB be trimmed obliquely. It is evident, in the first place, that since the impulse of the wind must be perpendicular to the sail, the vessel will not move in the direction of her length AB, but in some other line to leeward of it, as CE. Her head therefore must be kept to windward of her intended course. The amount of this deviation, viz. the angle BCE, is called the leeway. If the ship were a round tub, so as to be equally moveable in all directions, and fitted with a mast and sail in her centre, it is clear that, if prevented from turning round, she would constantly sail in the line CL, perpendicular to the yard. But from her construction she is much more easily moveable in the direction of her length than her breadth, and her course will therefore be somewhere between CL and CB; whatever be the amount of the impulse on the sail in the direction CL, the angle of leeway BCE will remain the same, for the impulse of the resisting surfaces will still be proportional. And this impulse must be in the direction CL, so long as the yard remains in the same trim, whatever be the direction of the wind, consequently, the shape of the vessel, and train of the sails alone are what determine the leeway, (except in so far as the wind acts on the hull and rigging), which, when the quantity of sail that can be carried is small, becomes a very important part of the whole impelling power. Therefore, did we know the proportionate resistance which a vessel makes to longitudinal and transverse motion, we might calculate the leeway for any angle of impulse. But in the small obliquities of action on the sides, the resistance, as we have seen, differs so much from theory, that no calculation can properly be formed. Besides, in common vessels, the form cannot be reduced to an equation, and the surfaces of action change with every variation in the direction of the impelling power. As matter of experiment, it is known that a good sailing ship, with all her sails in action, will not make more than from half a point to a point of leeway, that is, from 5 to 12 degrees. The amount increases as she is obliged to take in her sails, and in the shallow vessels employed in inland navigation, the lateral resistance being less in proportion, the lee-way must in general be greater. Hence it is an object with them to adopt inventions for increasing the lateral resistance without diminishing much their direct motion, such as the lee-boards used in Holland, sliding keels, or the like. But leaving this at present to be matter of experiment, we return to our investigation of the action of the wind on an obliquely trimmed sail. In the last figure, therefore, take CE to represent the motion of the ship, WC that of the wind, then the diagonal yC will be the relative direction and force of the wind on the sail DH, and its impulse, as in the former case, will be represented by the square of CG; draw the perpendiculars mE, WK; then because of parallels mC $=$ GK $=$ EC $\times$ sin. ECH, and CK $=$ CW $\times$ sin. WCH, and with the former notation EC $= v$, WC $= w$; then CG $=$ CK $-$ GK $= w$ sin. WCH $- v$ sin. ECH.

And the impulse on the sail will be

$$a\,p\,(w \text{ sin. WCH} - v \text{ sin. ECH})^2.$$

Now, the vessel having acquired uniform motion, this impulse will be equal and opposite to that produced by the water acting on the side of the ship in the direction LC, when the ship is moving with the velocity and direction CE. Let CL represent this impulse, or that of the wind on the sail, and reduce it into CM and ML, of which CM will represent the impulse in the line of the ship's length, and ML perpendicular thereto, that in the direction of the breadth, when she is sailing with the lee-way BCE, the surface or side of the ship exposed to the action of the water in the direction CL; then $q\,s$ is the impulse of the water,

$$\text{and } a\,p\,(w \text{ sin. WCH} - v \text{ sin. ECH})^2 = q\,s\,v^2$$

$$w, \text{ sin. WCH} = v\left(\text{sin. ECH} + \sqrt{\frac{q\,s}{a\,p}}\right)$$

$$\text{and } w. = v\left(\frac{\text{sin. ECH} + \sqrt{\frac{q\,s}{a\,p}}}{\text{sin. WCH}}\right)$$

$$\text{or, } n : v :: \left(\text{sin. ECH} + \sqrt{\frac{q\,s}{a\,p}}\right) : \text{sin. WCH.}$$

Where note, that by diminishing ECH, that is, trimming sharp, and enlarging a the quantity of sail in proportion to s the side exposed to the water, the third term of this proportion may be greater than the fourth, and therefore the velocity of the ship exceeds that of the wind.

It would be foreign to our purpose to pursue this investigation farther at present. We therefore shall now proceed to the modes of impulsion on which the reaction of the water has been employed to move the vessel.

Power of Oars.

When the oar is employed in navigation, the mode of calculating the power is not so simple as some authors have imagined. It is usually said to be a case of the application of the lever, from which, however, it differs in many particulars. The fulcrum, if the gunnel be taken as such, is moveable, the power itself moves with the vessel, and the water affords no fixed point of resistance. Bouguer, in his treatise on the construction of vessels, has discussed the subject but imperfectly, as is properly observed by Euler, who, in a *Memoire sur la force des Rames. Acad. Berl.* 1747, has given a complete solution of the problem. The memoir, however, of Euler, is too diffuse to be introduced here, and, as he himself has found necessary to omit various parts of his general solution in applying it to practice, we believe it will be better to give here a more simple view of the subject, which will at the same time be sufficiently correct for every useful purpose. In the boat AB, (Plate CCCCVIII. Fig. 4.) let the oar EF be supposed to work in the rowlock C, from the position ECF to the position gCh, and rejecting the slight elevation from parallelism, which is produced during the action of the oar, we shall suppose Eg and hF to be straight lines, parallel to the keel AB: of these Eg represents the path of the point where the hand is applied, and hF in like manner the path of the centre of the percussion of the oar's blade.

Now, since the action or impulse on the oar and on the vessel will be the same, whether the boat advances through the water, or be kept at rest in a stream, which proceeds with equal velocity in the opposite direction, let Ce be the space through which the boat passes, while the oar describes the angle F C h, then by drawing $p\,e\,q$ through e, parallel to GCh, it will exhibit the position of the oars at the conclusion of the stroke, and F q will be the space through which the oar actually passes in the water.

Then, if the relative velocity of the point F parallel to the vessel be expressed by w, that of the vessel by v, the actual velocity of the point F through the water will be $w - v$, and the resistance of the oar will be proportional to $(w - v)^2$. Let the surface of the oar blades $= s$, and let $m^2\,s$ be the surface of the boat's bow, or rather the plane which undergoes an equal resistance with the vessel. Also let $p =$ the impulse of water on a square foot of oar moving one foot per second, and r^2p the impulse on an equal portion of the bow, or equivalent plane, whence r^2m^2 will express the quotient of the resistance of the bow to the water, divided by the resistance of the water to all the oars moving with equal velocity.

We shall then have the impulse of all the oars as the square of their velocity through the water $(= w - v)^2 s\,p$, and the resistance of the vessel $= m^2\,s\,v^2 r\,p$. Wherefore, by equating these, as will be the case when the boat moves with uniform velocity.

$$(w - v)^2 = r^2 m^2 v^2, \text{ and } w - v = r\,m\,v,$$

$$\text{Also } (r\,m + 1)\,v = w, \text{ or } v = \frac{w}{r\,m +}$$

$$\text{Also } v : w = 1 : r\,m + 1 = \text{C}\,e : \text{F}\,h = \text{C}\,o : \text{CF},$$

$$\text{and } v : w - v : 1\,r\,m = \text{C}\,e : = \text{F}\,q - \text{C}\,o : o\,\text{F}.$$

As an example, suppose the resistance on oars per foot three times the resistance on the vessel's bow, or $r^2 = \frac{1}{3}$, also that the surface of the oars be only one-third of that of the bow, then $m^2 = 3$, and $r\,m = 1$. Also, $v = \frac{w}{2}$, that is, the velocity of the vessel relative to the water, will be one-half that of the velocity of the oar's blade relatively to the vessel. The first of these positions agrees nearly with experiment, for, by making the oar thin and broad, its resistance p will be nearly 1½ lb. per foot, whereas, in the sharp bow of a vessel, we have seen the resistance will not exceed ½ lb. per foot of the base or transverse section. But, in common rowing, this advantage is nearly counterbalanced by the circumstance of the oar only acting for about one-third of the time required for making the stroke. In such cases, therefore, if we suppose $r^2 = \frac{1}{3}$, we must reckon only one-third of the number of oars employed, and on this last example, we would have the entire surface of oar-blades equal to that of the bow, ere the above velocities would be obtained. In that case, the surface of the oar in constant action would be only one third of the bow of the vessel, and therefore $m^2 = 3$; or, we may suppose $v^2 = 1$, and reckon all the oars, we would have then $m^2 = 1 - v = w$.

Now suppose the surface of the oar-blade increased to four times the bow, or $m^2 = \frac{1}{4}$, $m = \frac{1}{2}$, also $r^2 = 1$, then $v = \frac{w}{1\frac{1}{2}} = \frac{2}{3} w$; and if $m^2 = \frac{1}{36}$, or $m = \frac{1}{6}$, then $v = \frac{w}{1\frac{1}{2}} = \frac{6}{7} w$ with oars of 36 times the surface of the bow.

Whence we see, that the velocity of the ship increases with the magnitude of the oars in comparison of her bow, but not in the same proportion; since quadrupling the oars of the first example increases the velocity only $\frac{1}{6}$, and increasing that again ninefold only adds $\frac{4}{21}$, or hardly one-fifth.

2d, If we increase the velocity w without altering the power, we must diminish the oar.

Let $w = 1$, and $m^2 = 1$, then $v = \frac{1}{1+1} = \frac{1}{2}$

$w = 2$, and $m^2 = 4$, then $v = \frac{2}{2+1} = \frac{2}{3}$

$w = 3$, and $m^2 = 9$, then $v = \frac{3}{3+1} = \frac{3}{4}$

$w = 10$, and $m^2 = 100$, then $v = \frac{10}{10+1} = \frac{10}{11}$.

Whence, in general, since the power applied will bear the square of the oar's velocity, and inversely as its size; therefore, with equal powers, the oar's size must be inversely as the square of the velocity; and, in that case, the velocity of the ship will increase, by diminishing the oar as far as possible, and increasing the velocity accordingly. Long light oars, therefore, without the vessel, are best, in opposition to the conclusions of Bouguer and others.

Our next enquiry is to the application of the powers used to the handle of the oar.

Let $h =$ the distance from the handle of the oar to the rowlock, or EC, and $n h =$ the distance CF from the rowlock to the centre of the blade.

Then, since $v : w :: \mathrm{C}\,o : \mathrm{CF} = 1 : r m + 1$,

And, $\mathrm{CF} : \mathrm{CE} = n h : h = n : 1$.

Therefore, $\mathrm{C}\,o : \mathrm{CE} = n : r m + 1 = v : t$ the velocity of the handle within the boat, the actual velocity being as $\mathrm{A}\,a + a\,\mathrm{E} = t + v$.

That is $t = v \frac{r m + 1}{n}$, and $v = \frac{t n}{r m + 1}$.

And $t = \frac{w}{n}$, $w = n t$.

Again, as to the power applied at the handle, $s p$ being the surface of one oar $(w - v)^2 s p$ is its resistance, and will be to the impulse on the handle as $t + v : w - v = \mathrm{E}\,p : \mathrm{F}\,q = \mathrm{E}\,o : o\,\mathrm{F}$.

Or since $w - v = r m v$, the impulse of the handle is $\frac{(r m v)^3 s p}{t - v}$ or $\frac{(r m v)^3 s p}{v\left(1 + \frac{r m + 1}{n}\right)}$

Since $t = v \frac{r m + 1}{n}$, or by reduction the impulse aforesaid will be $= \frac{v^2 r^3 m^3 n . s p}{n + r m + 1} = q$.

But again, as rowing is performed by persons within the ship, the reaction of their feet tends to drive the vessel backwards, and will be equal to the impulse which is applied to the handle. But this reaction acting on the oar at C, will be balanced by an increase of force in E, as $o\,\mathrm{E} : o\,\mathrm{C} = t + v : v$; therefore, taking the whole impulse on the handle $= x$, we have $x \times \mathrm{E}\,o = x \times c = x \times \mathrm{C}\,o + q \times \mathrm{E}\,o$, or $x = \frac{q \times \mathrm{E}\,o}{\mathrm{E}\,o - \mathrm{C}\,o} = q \times \frac{\mathrm{E}\,o}{\mathrm{EC}} = q \frac{t + v}{t} = \frac{q + v}{t} q = \left(1 + \frac{n}{r m + 1}\right) q = \left(\frac{m + 1 + n}{r m + 1}\right) \left(\frac{v^2 r^3 m^3 n s p}{r m + 1 + n}\right) = \frac{v^2 r^3 m^3 n s p}{r m + 1}$.

For an example, take the galley mentioned by D. Bernoulli, which had 260 oars of half a square foot each, and the distance of the handle and blade from the rowlock were as 1 to 2. This galley, by its oars, rows $7\frac{1}{5}$ feet per second, and by the weight of a cubic foot of water, it was moved 2 feet per second.

Now, taking the weight of a cubic foot of water, which produces the velocity of two feet, as being equal to 64lb. we have the impulse on the bow at one foot per second, equal to one-fourth of this, viz. 16lb. also of the 260 rowers, only one-third, or 86, could act at once on the surface, equal 43 square feet; and the impulse on this at $1\frac{1}{2}$ lbs. is 64 lbs. nearly; wherefore, $r^2 m^2 = \frac{16}{64} = \frac{1}{4}$, or $r m = \frac{1}{2}$, $n = 2$, and $v = 7.2$ feet.

Therefore, to find the velocity of the handle within the galley, $t = v\left(\frac{r m + 1}{n}\right) = 7.2 \times \frac{1\frac{1}{2}}{2} = 5.4$, five and a half feet nearly.

Also $w - v$, or the velocity of the blade through the water, is equal to $10.8 - 7.2 = 3.6$ feet only, or $w - v = \frac{1}{2} v$.

The impulse of the blade of one oar is equal to $(3.6)^2 \times \frac{1}{2} \times 1\frac{1}{2}$ lbs. $= 9.72$ lbs.

The actual velocity of the handles is equal to $t + v = 7.2 \times 5.4 = 12.6$ feet.

And the actual force applied to the handles $= x = \frac{v^2 r^3 m^3 n s p}{r m + 1} = \frac{(7\frac{1}{5})^2 + \frac{1}{8} \times 2 \times \frac{1}{2} \text{ lbs.}}{\frac{1}{2} + 1} = \frac{51.84}{8} = 6.48$ lbs.

Also in this case $\mathrm{E\,C} : \mathrm{C}\,o :: 3 : 4$, and $\mathrm{C}\,o : o\,\mathrm{F} :: 4 : 2$.

So that four-sevenths of the force is employed in overcoming the reaction of the rowers, and only 2.776 lbs. employed in overcoming the resistance of the water; but then this 2.776 lbs. is enabled to act with a proportionally greater velocity, viz. 12.6 feet, while the apparent power is 6.48 lbs. moving 5.4 feet.

Observe, that besides the above, a considerable force is employed in overcoming the inertia of the oar, and in making the returning strokes.

These forces may be calculated on similar principles, but it would extend our investigation too far. In the above example, the circular velocity of the blade being w, its actual velocity in the returning stroke would be equal to $w + v$, or $10.8 + 7.2 = 18$ feet per second, and the resistance of the air being $\frac{1}{500}$ lbs. at one foot per second, that of 260 oars, or 43 feet at a time, would be $\frac{182 \times 43}{500} = \frac{13932}{500} = 27.864$ lbs. constantly acting, which is nearly as much as the direct impulse on three of the oars during the stroke. Hence the utility of feathering the oars, by which the surface of the oar blade, being reduced to one-third at least, and that acting, from the shape of the oar edgeway, in the most favourable manner, the impulse on it will not exceed an half of the former, or $\frac{1}{1000}$ lb. per foot, whence the whole reaction from the oar during the returning stroke will not exexceed $\frac{27.86}{6}$, or 4.64 lbs. not half the effect of one oar during the direct stroke. The effect of feathering is still more important when going against the wind, since against a gentle breeze of 12 miles an hour, the above reactions would be quadrupled.

The investigation of the power of oars has become the more important, since the application of steam-engines to the propelling of vessels, by which discovery many of the inconveniences of open rowers are likely to be removed, and a new field opened for the extension of inland navigation. The usual mode of applying this power has been by means of the paddle, which is a series of revolving oars on one axis. This possesses the great advantage of admitting safely of any increase of velocity, without endangering the connection of their parts; on the other hand, an alternate motion can hardly be produced of sufficient rapidity, which would not have the effect of shaking itself to pieces. We have seen that the increase of velocity in the oar is of great importance, even where the power is the same. The points liable to injury are also greatly diminished. This increase of velocity is not limited as in the common oar, where the application of human power, and the difficulty of quick repercussion, oblige us, where great velocity is wanted, to have recourse to oars of great length, for the revolution of the paddle wheel may be made as rapid as we please, as its diameter may be increased in any degree; by which last means the loss arising from the obliquity of action at the beginning and end of the stroke may be lessened, and the effect of backwater on the wheel diminished by the increased centrifugal force communicated to the water. Here, therefore, is a rich field for the investigation of the mechanical philosopher, or scientific engineer, but one which we cannot at present enter far into.

It is obvious, that, though velocity in the propeller or oar be desirable, that it has its limits; for, in the first place, time must be given for the water to fall in after the oar or paddle, ere a new stroke be given, and therefore the paddles or oars should be as few as possible. They cannot be fewer than one; but probably two may be found most advantageous. A propeller of great radius will also be found inconvenient, in occupying too much space. The water should enter and be discharged from the paddle, as nearly as possible, in the tangent to the circle; and where waves occur, they should be prevented from rising against, and burying the paddle. Where the vessel works with sails and paddles, the means of equalizing the action of these last, as the vessel heels, must be employed. For, in heavy gales of contrary wind, the machinery will hardly be able to pull the vessel against it, and the mode of beating to windward with sails will be found of great importance. The propellers will destroy the leeway; and we know, that if the vessel can carry sail, she may, in such cases, run on the oblique course with a greater velocity than that of the wind.

Example of the Power of a Steam Vessel.

This vessel is built sharp, of 18 feet beam, and nine feet draft, exposing, therefore, about 80 square feet of bow, which, at half a pound per foot, is forty pounds pressure.

Her paddle wheels have six propellers, of 4 feet by 2, and reckoning one of these paddle boards in constant action on each side, we have 16 square feet of oar, which, at a pound and a half per foot, is equal to 24 pounds.

Therefore, $r^2 m^2 = \frac{40}{24}$, and $m r = \surd 1.66 = 1.29$.

Now, the mean circle of the paddle wheel is eight feet in diameter, or circumference equal to 25, and, when working at her speed, makes 30 revolutions per minute, or $12\frac{1}{2}$ feet per second $= w$.

Wherefore, $v = \frac{w}{r m + 1} = \frac{12\frac{1}{2}}{2.29} = 5.46$ feet per second, or about $3\frac{3}{4}$ miles per hour, for the velocity of the ship.

Now, suppose the paddle reduced to 1-4th, by making them only half the number and half the size, but their velocity doubled, which may be done by the same power,

We have one paddle of $2 \times 2 = 4$, and in the two wheels only one such paddle at once, or 4 feet of oar, which, at $1\frac{1}{2}$ lb. per foot, is 6 lb.

Whence, $r^2 m^2 = \frac{40}{6} = 6.6$, and $r m = \surd 6.6 = 2.58$.

But the velocity being doubled, w is 60 revolutions of 25 feet per minute, and $w = 25$ feet per second.

Hence, $v = \frac{w}{r m + 1} = \frac{28}{3.58} = 7$ feet per second, or about $4\frac{3}{4}$ miles an hour.

Thirdly, suppose the paddles reduced to two in number on each wheel, and of one-third the size, the diameter doubled, and the velocity increased one-half, or 45 revolutions per minute, which might also be done by the same power, and with much better effect, since the obliquity of action would be greatly diminished.

We have 1-9th of 24 lbs. $= 2\frac{2}{3}$ lbs. for the impulse of the oar at 1 foot.

Then $r^2 m^2 \frac{40}{2\frac{2}{3}} = \frac{120}{8} = 15$, and $r m = \surd 15 = 3.873$.

Also, $w = \frac{45 \times 50}{60} = \frac{150}{4} = 37.5$ feet per second.

And $v = \frac{37.5}{4.873} = 7.7$ feet per second, or $5\frac{1}{4}$ miles an hour.

So that, with the same power, the velocity of the vessel is increased one mile per hour by the first alteration, and half a mile more by the second.

And this increase of velocity is still more important, for this vessel likewise uses sails, by which her speed is sometimes increased to upwards of eight miles an hour, by which time her present paddles not only become useless to her, being unable to keep up with her motion, but are even a drag, and prevent her from exceeding this velocity.

Whereas, by the proposed alterations, this would hardly ever occur, since the paddles would continue to have some action, until her rate of sailing was 18 or 24 miles per hour.

But observe, that although we have said these increased velocities may be obtained by the same power, by diminishing the size of the oars in proportion to the increased resistance, yet the friction and inertia of the machine will greatly diminish this advantage, in consuming a portion of the power applied, and the small swift oars will be chiefly useful in being less exposed to injury.

To determine the pressure of the paddles in the above case, we have

$$w - v = 12\tfrac{1}{2} - 5.46 = 7.04,$$
$$a\,(7.04)^2 \times 16 \times 1\tfrac{1}{2} \text{ lbs.} = 1189\tfrac{1}{2} \text{ lbs.}$$

The steam engine is of 25 inches cylinder, or 20 horse power; and, taking the pressure on the piston at 10 lb. per circular inch, the entire pressure is 6250 lbs.

This piston moves with a velocity of 200 feet per minute, making 40 double strokes, of $2\frac{1}{2}$ feet each; the momentum per minute is therefore 1,250,000.

The paddle-wheel, moving 30 revolutions of 25 feet, is 750 feet per minute, which, multiplied into 1189.5 lbs. gives a momentum of 892,125.

Whence a momentum of 358,000, or $\frac{7}{25}$ of the entire power expended, is lost by the mode of application. And this loss is rather underrated, for, in fact, a much greater power than 10 lbs. per inch is required to give the wheels the velocity above mentioned.

Now this loss may be accounted for from various causes, to overcome the inertia of the machinery, and especially to convert the alternate motion of the piston into the rotatory motion of the paddles; also, to overcome friction. But the greater part of the loss is occasioned by the oblique action of the paddle, especially at entering and departing from the water, and in communicating the centrifugal force to the water, which, excepting at the after-part of the wheel, is of no use towards propelling the ship.

A steam boat is said to have been built in America, of 138 feet keel, and 300 to 400 tons burden, and to have run at the rate of 18 miles an hour; hence, from the common rule for tonnage, her section must be about $\frac{350 \times 94}{138} = 240$ square feet, and the pressure thereon $= 120$ lbs.

Required the power of engine to produce a velocity of six feet per second, or four miles per hour.

$6^2 \times 120 = 4320$, the resistance at four miles.

The resistance in last example being about 1200 lbs. and overcome by a 20 horse engine, would be about 60 lb. per horse power. Wherefore, in this case, with machinery similar to the last, a power of $\frac{4320}{60} = 72$ horse power would be required. And even if the machinery were as perfect as possible, it is not likely that the loss of power would be diminished above one half, viz. reduced from $\frac{7}{25}$ to $\frac{7}{50}$, being about a seventh in all, so that an engine of about 62 horse power might possibly be sufficient for the purpose. To produce a velocity of eight miles an hour would require an engine of four times the above dimensions, so that we must suppose the accounts of these great velocities are either spurious, or else that the progress of the vessel has been aided by wind or currents.

There are various other forms, in which the reaction of the water has been applied to the propelling of vessels. All of them admit of being explained and investigated upon the same principles as we have now done for the oar and paddle-wheel. Being not in general use, we shall at present only mention a few of these. It may be observed with respect to these, that though the means of propelling vessels through the sea, or in rough water, by machinery, be yet a desideratum, many methods may be given which would be sufficient for the purpose of river navigation, or in any smooth water where great velocities were not expected. But in this simplest case, it does not appear that any better mode has been found than revolving water or paddle-wheels.

The Chinese mode of working their river barges, which is much praised by many voyagers, is by sculling with one or more long heavy oars over the stern or quarters. This mode is very convenient in a crowded river; and, according to the report of travellers, appears as effectual as rowing. Similar in principle is the mode proposed by D. Bernoulli, consisting of planes parallel to the ship's side, which move on a vertical hinge or axis a little before their middle, so that whether the planes are pulled in towards the ship's side, or thrust out therefrom, one side will act obliquely backwards, and thus, by the reaction of the water, impel the ship. Instead of these, a revolving screw has been proposed, but found of little effect, though it would perhaps admit of improvement. Also, oblique vanes, like those of a wind-mill, or smoke-jack, revolving athwart the ship's hawse, or at her stern, have been proposed repeatedly. A Mr. Sloper, some time ago, obtained a patent for this mode of propelling vessels.

It is not easy to assign what may be the effect of these modes of oblique action, the resistance of fluids to oblique surfaces not being found to follow any known law.

According to the investigations of Kraft, and other mathematicians, the oars of Bernoulli appear to possess a considerable advantage over those commonly employed; but as we have not heard of their having been brought into use, it appears unnecessary here to notice them farther. It has been proposed, also, to move the same sort of oars by a rotatory, instead of an alternate motion, by which means they would probably be more durable, as not only the looseness of the hinge-work, but the loss of power in alternately overcoming the inertia of the apparatus would be avoided.

With respect to sculling, we suspect that the centrifugal force, communicated to the water, is of as much importance in impelling the vessel, at its oblique impulse on the blade. In the screw system, and that with oblique vanes, as well as in the common oar, this centrifugal force is lost, being exactly opposed by that on the opposite side of the ship's axis. A spiral blade, indeed, might be constructed, that would possess the property of turning this force to account. In any other form the lateral resistance of the water to any machinery, which is constantly immersed, must of itself be a considerable impediment to the progress of the vessel.

When the rapidity of the river, or other causes, will no longer admit of navigation by the sail or oar, recourse is had to tracking, or, where the river is not too deep, and unprovided with tracking paths, to boom-setting or poling, especially against the stream, for that of itself is usually sufficient for the navigation downwards, though instances occur on slow running rivers of tracking being used either way. In canals, also, tracking is the usual mode employed for impelling the vessel, and, therefore, the same investigation will serve for that case.

Tracking is performed by men or horses; and if their habitual efforts were either constant, or bore a regular proportion to the velocity, we might easily form an equation, by means of which, from the section of the vessel and proposed velocity, the number of horses or men may be found; but in all operations performed by animal force, it is to be observed that the animal has not only to overcome the proposed resistance, but also to put his own body or members in motion; and if the velocity be great, this last part will exhaust the whole of his power. Thus the race-horse can do little more than move himself, while the drag-horse can transport with him a load of at least a ton. The greatest power is exerted by an animal when no motion is required, or at a dead pull; but no work is thereby effected. His greatest velocity is obtained when at his speed, and completely unloaded. Between these extremes, therefore, in which no profitable result is obtained, there is a certain velocity which produces the greatest mechanical effect. We should, in the application of animal labour, therefore, so contrive our rate of motion that this maximum of effect may be obtained.

In the case of still water navigation, the velocity of the animal, and of the load or vessel are necessarily equal, and much depends on circumstances and the nature of the cargo, whether a smaller quantity with greater speed, or a greater at little expence, though slower, be the most advisable mode of transport.

Chapman, in his observations on canal navigation, p. 73, says, he has observed a boat of light construction, with only 14 tons lading, 8 feet width of floor, about 10 feet width of water line, and 50 feet extreme length, drawing two feet three inches water, and sharp at the ends, dragged against a stream, whose velocity was 5½ English miles an hour; and although there were 28 trackers, besides three men in the boat poling it on, it only advanced at the rate of one-fourth of a mile an hour. The resistance was not much increased by contraction of the water-way either in width or depth. In this case, therefore, the progress through the water was 5¾ miles per hour, or about $8\frac{13}{30}$ feet per second, the force of the trackers being exerted in the most favourable manner, seeing they had to advance on the ground only at the rate of one-fourth of a mile per hour, or one foot in three seconds. Yet, in this case, taking the resistance on the bow for one foot per second, as formerly at ½ lb., the actual resistance per foot in that velocity will be 35½ lbs., and for 20¼ feet of bow, or cross section, is 718 lbs., which being divided among the whole number of trackers and polers, taken as 30, will be about 26 lb. of direct resistance overcome by each. This resistance, increased in the proportion of the secant of the obliquity, will give the direct force applied by each man to the track rope. It is probable that this obliquity was such as might increase the force one-third, or to about 35 lb. per man.

This power is greatly below that commonly stated by authors; but perhaps may be assumed with more safety in a calculation of this kind than any higher average; for where many men are employed together, their individual action is considerably below what may be done by each working alone. At the above rate of action, the proportion for a horse, reckoning 5 horses equal to 30 men, would overcome a resistance of 150 lbs. on the boat's bow, or 175 lbs. on the track-rope.

As another example, take the case of two boats, said by Smeaton to be drawn by one horse along a canal of three feet deep, 50 feet average section. The average section of each boat is about 20 square feet; they proceed along the canal at from 2 to 2½ miles per hour, average 2¼ miles, or $3\frac{3}{10}$ feet per second. This velocity, along a canal of 50 feet clear, will make the water pass along the boat's side in the diminished channel of 30 feet, with a velocity of 5½ feet per second, which at the former rate of resistance, viz. ½ lb. per foot and second, will be 15⅛ lbs. on each foot of bow, 302½ lbs. on each boat, or 605 lbs. on the two. These boats are in length four times their breadth, and fifteen times their draft when loaded. But the above rate of tracking gives a resistance far greater than we can suppose a horse able to overcome, so that there must be some mistake. Even in open water, the velocity of $3\frac{3}{10}$ feet per second, would produce a resistance of $5\frac{4}{9}$ lbs. on each square foot of bow, and of 218 lbs. on the two boats, which, if increased by the obliquity of direction, and the adhesion or friction of the side, will still be a high average. It may however be remarked, that this contracted channel, and consequently the increased velocity, only takes place after the water has passed the bow of the vessel, and that, therefore, the increased resistance due to 5½ feet velocity, does not take place at the bow, although indeed there may be an increase of friction on the sides, a cause of resistance which we have not thought necessary to bring into our estimate hitherto, though doubtless of considerable importance, especially in narrow canals. But to produce the increased velocity, the water must begin to accelerate, even in its passage along the bow, so that there can be no doubt but a considerably greater resistance than that already stated for open water would take place in the example alluded to. It is probable again that the pressure on the bow of the after-vessel would be much diminished by following immediately in the wake of the other.

We may give another example from Smeaton.

Vessels of 13½ feet wide, 3 feet draft, are drawn on a river at the rate of two miles an hour, *i. e.* three feet per second. This will give 180 lbs. for the resistance on the bow. A number much nearer to the power of the horse than that in the preceding example. If we suppose it increased one-third for obliquity of the line of traction, we have 210 lbs. And, according to Desaguliers, a horse may draw 200 lbs. at the rate of 2½ miles per hour for 8 hours per day, when with 240 lbs. he can only work 6 hours per day.

The first example gives an idea of the current at which farther tracking upon rivers must necessarily become impracticable, or at least unprofitable; the 28 trackers transported 14 tons, that is, each person transported 10 cwt. but at the rate only of one quarter of a mile per hour. Now, seeing each man would with ease carry one hundred weight with ten times this velocity, at the rate of 2½ miles per hour, or faster, it is evident that if the load admitted of proper subdivision, there was no need of the navigation, since the most economical way was for the trackers to carry the load overland. Whenever, therefore, the velocity of the river exceeds 5½ miles per hour, we may suppose all ascending travel to cease; and, as is the case in the great rivers of Poland and Russia, it may not even be worth while to bring back the boats that are employed to take the produce of the interior down to the coast, while the men may be employed to return overland with some of the tackling.

The slope and elevation which is required to produce this velocity will depend on a variety of circumstances. It will be much less in great rivers than in small. In the former the mass of water being greater, the friction of the bottom has less effect. The sinuosities are larger, and of course fewer in the same space, since a river of half the width may take double the number of windings. They are also more gentle for the same reason. Much will also depend on the regularity of the section, whether altered by contractions and enlargements in the breadth or depth, which, by requiring an increase of velocity through the contraction, to compensate for the decrease through the enlargement, will consume a portion of the fall of the river in regenerating this velocity. Again, asperities or obstructions, whether at the sides, or in the bottom, will produce eddies behind them, by which, not only is the current retarded, but in great slopes a means afforded of navigation against the stream, when that would be otherwise impracticable, in slopes for instance of even ten feet per mile.

Of these causes we shall, at present, only enquire into the effects of depth and flexure. The velocity is nearly proportional to the square root of the hydraulic mean depth, and of the sine of inclination, jointly; that is, to the square root of the mean depth, multiplied into the fall and divided by the length, or $v \div \sqrt{d\,s} \div \sqrt{\frac{d\,f}{l}}$, where d is the hydraulic mean depth, s the sine of inclinations, f the fall, and l the length. From the researches of Buat and Young (see HYDRODYNAMICS) it appears that the velocities per second in French inches gives $v = \sqrt{80.000\,d\,s} = 200\sqrt{2\,d\,s} = 200\sqrt{\frac{2\,d\,f}{l}}$ nearly, and assuming $v=6$ miles an hour, or 9 feet per second, or 100 inches, as the limiting velocity for tracking, we have then $100 = 200\sqrt{\frac{2\,d\,f}{l}}$, whence $\sqrt{l} = 2\sqrt{2\,d\,f}$, and $l = 8\,d\,f$.

Now taking $l=1$ mile, or 5280 feet, we have

$$f = \frac{5280}{8\,d} = \frac{660}{d},$$

Taking the lowest horizontal depth at 5 feet or 60 inches French, then $f=11$ feet per mile.

Taking the depth at 20 feet the fall would be only 2¾ feet per mile.

The velocity per second in inches, $v = \frac{\sqrt{(a\,d\,s+c^2)}-c}{a}$, where d is the diameter of the pipe, or four times the hydraulic mean depth, s the sine of inclination, or $\frac{h}{l}$, a a coefficient, expressing that part of the friction proportional to the square of the velocity, c a similar coefficient for that part proportional to the simple velocity. These coefficients are variable according to the depth. The following is a brief table of their values, abridged from Dr. Thomas Young, *Phil. Tran.* 1808, and sufficient for the present purpose:

d	a	c
1	.000025	.000110
2	28	.000077
5	31	51
10	34	41
20	36	48
50	39	77
100	40	92
200	40	95
500	41	94
1000	41	90

But again, since

$$v = \frac{\sqrt{(a\,d\,s+c^2)}-c}{a}$$

$$\text{Then } s = \frac{v^2\,a+2\,v\,c.}{d}$$

And if we assume $v=100$ inches as the limited velocity of tracking, we have, in a depth of 25 inches, where $d=100$, $v^2\,a=40$, $2\,v\,c=\frac{.0184}{.4184}$, and $\frac{40+\frac{.0184}{.4184}}{100} = .00418 = s$; and this, multiplied by 5280, gives 22 feet nearly per mile. Also seeing that a and c are little altered in these great depths, we have the fall inversely as the depth nearly, so that a mean depth of 25 feet would require a fall of $\frac{22}{12}=1$ foot 10 inches only for the same velocity.

But it is probable that these theoretical values are vastly too high for the great rivers; for, according to experiments made on the Ganges, by order of Mr. Hastings, (*Phil. Tran.* 1781, p. 87,) a section of the ground, parallel to one of the branches, and 60 miles in length, was found to have nine inches fall in a mile in a straight line; but the windings of the river were so great as to reduce it to four inches per mile along the stream. This was, in the dry season, the mean width of the river 3-4ths of a mile, its mean depth 30 feet, and the velocity somewhat less than three miles an hour. But during the inundation, the river runs in its channel at the rate of five or six miles per hour, which is easily explained on account of its increased depth; for, at the same time, the boats are enabled to pass upward over the shallow waters of the inundation, which run little more than half a mile per hour.

If we try the velocity due to the above-mentioned state of the Ganges, by the table above given, we have $d = 4 \times 30 \times 12 = 1440$, $s = \frac{1}{3\times5280}$, $a = .000041$, and $c = .000090$.

Whence, $v = \frac{\sqrt{(a\,d\,s+c^2)}-c}{a} = 45$ inches nearly for the velocity per second, or about two miles and a half per hour nearly.

This, however, it is to be observed, is the mean velocity of the stream; the superficial velocity is what we have to do with, and is also that above noted. It will, according to Young and Buat, exceed this by the square of the mean velocity, viz. $45+\sqrt{45} = 51.7$ inches per second, or 2.94 miles per hour, agreeing extremely well with the observation.

During the inundation, the hydraulic depth of the river is probably doubled, the river having thrice the velume of water in it, and since it runs about five or six miles an hour, we may take

$$v = 100 \text{ inches, and } d = 4 \times 12 \times 60 = 2880.$$

Whence, $5280\,s = \frac{v^2 a + 20\,c}{d} = 78$ feet, or 9.4 inches per mile, being very nearly that found by leveling across the country.

We may try the same examples by the elegant concise theorem of Eytelwein.[*]

The superficial velocity is nearly a mean proportional between the hydraulic mean depth, and the fall in two miles. Whereas, the fall per mile is a third proportional to twice the hydraulic mean depth, and the velocity per second.

Therefore, in velocities of 100 inches per second, we have, in the depth of five feet, a fall of $\frac{1000}{120} = 83\frac{1}{3}$ inches nearly.

At 25 inches deep $\frac{10000}{50} = 200$ inches, or $16\frac{2}{3}$ feet.

25 feet deep $\frac{10000}{600} = 16\frac{2}{3}$

35 feet nearly $\frac{10000}{833} = 12$

On the whole, therefore, we may assume the fall of one foot per mile is sufficient to prevent trackage up rivers 30 feet deep, and in shallow rivers a greater fall may be overcome in the inverse proportion of the depth, so long as the river continues navigable. When the want of water, or the excess of fall, puts a stop to the navigation, other methods of overcoming the ascent must be reverted to, as we shall shortly explain.

But, ere we leave the subject of tracking, we may inquire into the most economical mode of its application. It is established by writers on dynamics, that the work done by an animal is greatest, when the velocity with which it moves is one-third of the greatest velocity with which it can move, when not impeded; and the force then exerted is four-ninths of the utmost force the animal can exert at a dead pull.

Now, the utmost force of a man at rest is, according to the best observations, about 70 lbs. and his greatest walking velocity about six feet per second, at a medium, consequently $\frac{6}{3} = 2$ feet per second, or about $1\frac{1}{2}$ mile per hour, is the velocity at which he should move, hence $\frac{4 + 70}{9} = 31\frac{1}{9}$ lbs. is the force he will exert when acting to the greatest advantage.

The power of a horse is usually reckoned at about six times that of a man, or about 420 lbs. at a dead pull. His utmost walking velocity is about nine feet per second: hence $\frac{9}{3} = 3$ feet per second, or about two miles per hour, is the rate at which he should, and $\frac{4 \times 420}{9} = 186\frac{2}{3}$ lbs. is the force he will exert when working most effectually.

These numbers, it will be observed, are not very distant from those formerly assigned from practical examples above given. Whatever be the velocity of the current, the tracking power and load should, in general, be adjusted so as to obtain these velocities.

If other velocities are proposed, it will be necessary to alter the force nearly in the duplicate proportion of the differences between the proposed velocities and the greatest velocity which the animal can move with when unloaded. Thus, suppose the greatest velocity equal V, the supposed velocity v, the forces will be nearly $\mathrm{F} \div (\mathrm{V} - v)^2$.

Suppose the force required which will be exerted by a horse moving three miles an hour, or about $4\frac{1}{2}$ feet per second.

$$(9 - 3)^2 : (9 - 4.5)^2 = 6^2 : 4\tfrac{1}{2}^2 = 186\tfrac{2}{3} : 105 \text{ lbs.}$$

the force at three miles per hour, which is considerably higher than exhibited by the experiments of Mr. More on a horse ploughing; the resistance found by him being only from 70 lbs. to 80 lbs. when the horse was moving at the rate of three miles.

Suppose next, that the horse should only move at the rate supposed to be proper for men, viz. 2 feet per second, we have,

$$(9 - 3^2 : (9 - 2)^2 :: 186\tfrac{2}{3} : 254 \text{ lbs.}$$

for the force which the horse will exert being more than the power of eight men, instead of six, which is the proportion for a dead pull. This difference is owing to the superior velocity of the horse; and if we calculate the power which would be applied by men moving at the velocity proper for the horse, the superiority of the horse labour in the case of tracking will be still more manifest; for,

$$6 - 2)^2 : (6 - 3)^2 :: 31\tfrac{1}{9} : 17\tfrac{1}{2} \text{ lbs.}$$

the force of each man at that velocity being little more than the eleventh of the power of the horse.

By multiplying the forces into the several velocities, we will see the proportion of effect on works done at the several rates; which, for the horse, will be

at 2 feet per second, $254 \times 2 = 508$
3 feet $186\frac{2}{3} \times 3 = 560$ maximum
$4\frac{1}{2}$ feet $105 \times 4\frac{1}{2} = 470$

Size of Boats.

The most economical load, and velocity of traction, being thus ascertained, the size of a boat may be readily adjusted thereto. For, dividing $186\frac{2}{3}$ by $3\frac{2}{3}$ equal to the square of the velocity in feet per second, we have 21, nearly, for the pressure at one foot per second, and valuing that, as before, at half a pound per foot square, 42 square feet appears the area of the section of a boat to be tracked by a single horse in still water. The bow being made of a favourable shape, the breadth and depth will be adjusted by other circumstances, and the boat should be as long as possible, since that will have less effect in increasing the resistance. Where very long boats cannot be employed, on account of the difficulty of turning, &c. sundry short boats are linked together in a string, rather than employ a single horse boat of greater section.

As to the limits of length, it is obvious that the friction only will increase by the prolongation of the vessel. The form of bow and stem being the same, ought to cause the plus and minus pressures, or head and stern resistances, to remain nearly unaltered. It would appear, however, from experiments, that, to a certain extent, the whole resistance to the vessel's motion is actually diminished by an increase of length only. This diminution is most palpable in square-ended vessels, a parallelopiped, whose length is ten times its breadth, moving more easily in a direct line than one of less length. But even in sharp-ended vessels, the sides of which more nearly correspond with the path of the watery filaments, the improvement holds good, at least until the length be four or five times the breadth of warping.

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[*] Handbuch der Mechanik und der Hydraulik.

Besides the methods already mentioned for open river navigation, there is still another mode occasionally employed, and which is somewhat analagous to the last-mentioned; we mean that of warping to find anchors or moorings, which are successively removed to higher parts of the stream.

Where the force is applied by hauling the warp along the gunnel, or winding it in by a capstan or windlass, the effect being exactly similar to tracking, may be calculated upon the same principles. A man at a winch will exert 30 lb. at the rate of 2½ feet per second, which is more than he can do in tracking. By tugging the warp, or working as in ringing or towing, he will do perhaps one-third or one-fourth more than at the winch, and most of all when ascending stairs and acting by the weight of his body. So that the walking wheel, or coal-heaving operation, seems not an injudicious application of human labour.

But in warping up rivers, it has been sometimes proposed to make use of the descending course of the current itself, to perform or facilitate the operation, and there may be cases where this could be employed with good effect. In the *Machines approuvées par l'Academie des Sciences*, there are a variety of proposals for this purpose. In one of them the warp is passed through a pulley at the mooring, and attached to a light boat, which, being made to expose as much surface as possible to the current, by its descent tows up the loaded barge. In another, water wheels or paddle wheels are placed on the vessel's sides, and, being turned by the current, wind up the warp upon their axle; and, in shallow rivers, booms or poles pushing against the bottom are proposed, wrought by those wheels either by racks, mast-ropes, or cranks. This last idea has been improved, and lately applied, by Mr. Brunton of Butterley, to a locomotive steam-engine for a common road. Another method is, to work a spiked roller or spoke-wheel along the bottom, either drawing the vessel after, or pushing it before—an idea which has also been employed by Mr. B. Chapman of Newcastle, to locomotive steam-engines. These last modes are not likely to be of much use in rivers, chiefly on account of the irregularity of the bottom and depth of water; but the aforementioned method of warping may, at times, be valuable, since it will, in general, be easy to transport the anchors in the small boats which are usually employed with river barges. Unless with respect to the strength of the warp or cable, the velocity of the current in such a case will not be at all inconvenient, since its action on the water wheel will keep pace with that of the bow of the vessel. With respect to the proportions, it is obvious, that allowing one float-board at least to be in constant action, when the proportion of that to the bow of the barge is the same as that of the virtual radius of the axle on which the warp is wound, to that of the water-wheel, reckoning, of course, from the centre of percussion of the float-board and the centre of the warp. In this case, we say, the resistance on the wheel and bow being reckoned the same, the vessel will stand still; but we have seen, from experience, that, with equal velocities, the resistance on the bow will be only about one-third of that on an equal surface of the float-board. The water wheels will therefore be turned by the current, and, consequently, warp up the vessel. Suppose the wheel to revolve with one-third the rapidity of the current, when it will be working to the maximum, the resistance will be four-ninths; and, the pressure per foot being three times that on the bow, with equal velocity, the whole will be $\frac{12}{9}$ that on the bow. This will be counterbalanced by the resistance on the bow when the barge moves up the stream with the velocity $= \sqrt{1\frac{1}{3}} = 1.16$, or about one-sixth of the velocity of the stream along the river. Or thus:

Let s, the velocity of stream past barge and paddles, $\frac{1}{n}$ of s, then $\frac{n-1}{n}\,s =$ velocity of paddle through water.

$$\text{Then, } p\,s^2 = 3\,p\left(\frac{(n-1)s}{n}\right)^2 \text{ the resistance}$$

$$3(n-1)^2 = n^2$$

$$(n-1) = \frac{n}{\sqrt{3}}$$

$$n = \frac{\sqrt{3}}{\sqrt{3}-1} = \frac{1.732}{.732} = 2.36.$$

That is to say, the paddles will balance the resistance on the bow, when their surface, being inversely as the velocities, the velocity of the paddle is $\frac{1}{2.36}$ that of the stream.

But it must be observed, that the barge moving up the stream produces an additional impulse on the paddles; so that if these be arranged to overcome the stream at all, they will overcome it in any velocity, and the progress of the barge upwards will go on accelerating.

Where the vessel ascending has its resistance counterbalanced by that of another light vessel descending, it is evident that the motion will be uniform, and must necessarily be slower than that of the stream, that the descending boat may receive any impulse. The rate of motion may be readily calculated from the relative surfaces exposed to action.

This species of navigation deserves more attention than it seems to have received. All rivers which are floatable may be made navigable in this manner, at an expense, in general, greatly less than any sort of canal may be made near them. The principle is used frequently on railways, as shall be afterwards explained, and the extreme case of a descending and ascending boat, being made to balance each other at a perpendicular lift, has been often suggested as a means of extending the benefits of canal navigation.

In shallow rivers, with sandy or moveable bottoms, the descending force of the current is sometimes employed to urge on a plank, kept upon edge, and acting as a snow plough, to form a temporary channel through the sand for the passage of a fleet of barges. This operation, called "chevaler" by the French, is common on the Loire, &c. and is sometimes found necessary for miles together.

Contractions.—We formerly observed, that where rivers are obstructed by shoals, the navigation may be preserved by a contraction of the channel. The rapid thereby formed will have deep water, even where the bottom is not corroded, since a head or accumulation of water will take place above. The vessel may, if necessary, be warped through this contraction by machinery, or hauled through by men. This is the Chinese mode of navigation, and has the advantage of being speedy, though rather dangerous for the descending trade. In this way mill-weirs are frequently found useful, in prolonging the navigation of a river of considerable slope, and the mill itself furnishes also a power for towing the ascending boat through the rapid. The head of water produced by such contractions, may be calculated on the principles employed for the table in the article BRIDGE, in this work, formerly referred to, and an opportunity will hereafter occur for discussing the subject more at large.

Flashing.—A more useful mode, in shallow streams, is to create an artificial flood for a time, by penning up the water in the river itself, or in side reservoirs, which may be opened when the boats are passing. This mode is called flashing, and is in use in the Cam, and various streams in England. It is also employed at the canal in Vishney Valshok, in Russia, by which the communication between the Volga and Neva is effected, and in many other parts of the continent. It is chiefly useful in shallow rivers of gentle fall, where the trade does not afford the expense of a canal; and the injury arising from these floods is of little consequence. Where the trade is entirely a descending one, as in the floating of timber, there is hardly any other mode of transport so convenient. It is employed frequently in woods of the Scots Highlands, and, we believe, was introduced there by Aaron Hill, the poet.

But by far the most remarkable specimen of inland navigation, carried on in this way, by contractions and flashes, is the great canal of China. That nation has not yet discovered the advantage of the European lock; and their operations in this art, however extensive and important to their empire, have been hitherto confined to a mere imitation of the process of nature, in the navigation she affords on their great rivers. It is to be regretted, that of the travellers who describe their justly famous canal, there has never been any acquainted with practical engineering; so that, instead of a plain, intelligible description, we are commonly presented with inflated accounts of the magnitude, rapidity, and ramifications of this canal, which, after all, appears only to be a series of cuts, in comparatively easy ground, connecting various lakes, into which various streams are brought, to give a navigable depth of water, and which is rudely regulated by overfalls and floodgates, to prevent the too great excess or diminution.

This canal, as we have formerly mentioned, gives, in conjunction with the natural rivers of that country, an inland navigation, except in times of flood and drought, from the north to the south of that great empire, through 16° of latitude. The following account of Lord Macartney's Embassy from Pekin to Canton, as given by Sir George Staunton, enables us to form some idea of the Chinese navigation.

"The embassy embarked on the river Pei-ho, at Tong-schoo-foo, about 12 miles from Pekin, in covered barges of about 70 feet length, and 15 feet width, and only about 10 inches draught of water, with their passengers, and such portion of their baggage as they took on board. The river was then become so low as to cause the boat to be dragged with difficulty over several of the shoals. After 60 miles of navigation they arrived at the tide-way, and in 30 miles farther, arrived at Tien-sing, (about 60 miles from the sea, or Gulf of Pee-chee-tee,) at the confluence of three rivers, up one of which the Yun-leang-ho, or Eu-ho, running from the south, they proceeded in the beginning at the rate of about a mile an hour, against a strong current, by the force of 18 or 20 trackers, as the river was confined within narrow bounds between two artificial banks, for the apparent purpose of giving depth. Above it was wider, deeper, and more gentle. Up this river they proceeded nearly 2½ degrees of latitude to the city of Lin-sin-choo, where they entered the Imperial Canal, which is carried in a line almost directly south, and nearly parallel to the general line of the sea-coast. This enterprise, the greatest and most ancient of its kind, which was found to extend from Lin-sin-choo to Han-choo-foo, in an irregular line of about 500 miles, not only through heights and over valleys, but across rivers and lakes. It is said by Sir George Staunton, to be 'often winding in its course, of unequal and sometimes considerable width, and its waters seldom stagnant.' On its junction with the Eu-ho, the canal was cut through ground of the height of 30 feet, to permit its water to flow with a gentle current into the Eu-ho. The current of the water was mostly slow; and, to prevent its running off too rapidly, its descent is occasionally checked by flood-gates, which were seldom so near as within a mile of each other. These flood-gates consist of two abutments of stone, one projecting from each bank, leaving a space in the middle just wide * enough to admit a passage for the largest vessels employed upon the canal. Few parts of the canal are entirely level; and they have overflows or passages through the banks, to prevent the water rising beyond a given extent; and also to prevent unnecessary waste of it through the flood-gates, the passages are occasionally closed by planks let down transversely and separately one above another, their ends resting in a vertical groove in each abutment. 'Some skill is requisite in order to direct the barges through them without accident. For this purpose, an immense oar projects from the bow of the vessel, by which one of the crew conducts her with the greatest nicety. Men are also stationed on each pier, with fenders made of skins, stuffed with hair, to prevent the effect of the vessels striking immediately against the stones in their quick passage through the gates, which are only open at certain stated hours, when all the vessels collected near them in the interval pass through on paying a small toll. The loss of water occasioned by the opening of the flood-gates is not very considerable, the fall at each seldom being many inches, which is soon supplied by streams conducted into the canal from the adjacent country on both sides. The fall is, however, sometimes above a foot or two, when the distance between the flood-gates is considerable, or the current rapid. The canal was traced often in the beds of ancient rivers, which it resembled in the irregularity of its depth, the sinuosity of its course, and the breadth of its surface, when not narrowed by a flood-gate. Wherever the circumstances of the adjacent country admitted the water in the canal to be maintained in a proper quantity, without any material deficiency or excess, by means of sluices managed in its sides, for the purpose of influx or discharge, as was the case farther to the southward, few flood-gates were necessary to be constructed, nor were there, any where, met with more than half a dozen in a day.'

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* "The width, according to the plate, appears to be little more than 21 feet; according to De la Lande, less than 30 feet."

" On the highest part of the canal which, by the map, is about one-fifth of its entire length in proceeding from the north, ' the river Luen, the largest by which the canal is fed, falls into it with a rapid stream, in a line which is perpendicular to the course of the canal. A stout bulwark of stone supports the opposite western bank; and the waters of the Luen striking with force against it, part of them follow the northern, and part the southern course of the canal.'

" In proceeding from the summit to the south, the canal or artificial river passed by the verge of the lake, and was there supported on high embankments, to enable it to pass over some rising land farther south, through which it runs at least 20 feet below the surface of the adjacent ground. The canal afterwards passed collateral to the lake of Wee-chang-hoo, which reminded the ambassador of the great canal of Russia, with which he was well acquainted. This ran in like manner, at certain distances, parallel to the lake Ladoga, from which it was separated by vast earthen embankments." From this circumstance it is possible that Peter the Great (although his genius was equal to the suggestion of any thing useful to his country,) may have borrowed the idea from China, as, previous to the formation of the canal of Ladoga, he had a direct acquaintance with the Chinese empire by an embassy, in the commencement of his reign, in the year 1693, whilst his brother John shared the throne conjointly with him.

" At a further distance, the canal widened, flowing to the southward in a current of upwards of two miles an hour. Several branches went off from the main trunk of the canal, on which, as well as on the distant lakes, several barges were seen sailing. During the next stage, the canal was conducted again through low grounds, subject to inundation, with lakes and morasses intervening.

" It then approached the Yellow River, into which it falls by a gentle current. The canal is here about three quarters of a mile in width, and forms an excellent harbour for the vessels navigating it. The Yellow River has here run through a course of 2200 miles, and is not more than 70 miles from the sea: ' Its width little exceeds a mile, and its depth in the middle of the stream is not more than 9 or 10 feet, and its velocity is about 7 or 8 miles an hour,' which it appears to continue downwards, consequently there is a considerable fall to the sea, which enables a descending branch to strike off southwards to the river Kiang. ' On the southern side of the Yellow River, the yachts began to proceed more quickly; the current of the canal, as it quitted that river, being more rapid, in consequence of which the number of flood-gates were increased upon this part of it; farther on it was carried by the margin of the lake Payo-yng, whose surface was much lower than that of the canal, which was separated from the lake by a strong embankment. Beyond the lake there was again swamps and morasses.'

" In the midst of the low grounds of this part of the route, a town of the third order was situated; the tops of its walls being little more than level with the surface of the canal, which formed an aqueduct raised 20 feet, was 200 feet in width, and ran at the rate of three miles an hour. This canal, on proceeding somewhat further, ceased to have a current; and the ground rising to the southward, it was found necessary, in order to give level, to cut down about 20 feet deep for a track of 7 or 8 miles, to a large city, where not less than a thousand vessels, of different sizes, were lying at anchor."

From the preceding extracts, an idea may be formed of the magnitude and diversity of this great canal, as to width and velocity of current, which, being variable, frequently in counteracting degrees, viz. often narrow in deep cutting, where the water is nearly stagnant, and wide where the stream runs with considerable velocity. It follows, that to give depth in the rapid streams, additional rivulets must be taken in, and discharged again in the commencement of the stagnant parts, which, it appears, is their mode of proceeding, as they have overflows to discharge their superfluous water, which is frequently applied to irrigation; and they repeatedly receive additional influx where it is necessary.

" The Kan-kiang-ho is then navigated for 300 miles, mostly against a strong current, to the foot of a ridge of mountains, separating it about 30 geographic miles, in a direct line from the navigable part of the river Pekiang, which runs through 260 miles to Canton.

" These rivers were navigated in their higher or shallower parts by the embassy, in lightly constructed covered barges, and described in one place to be sharp built at the ends, flat-bottomed, about 12 feet broad, and 70 feet in length; they sailed well, used cotton sails, and drew very little water, and, with a brisk and favourable breeze, made no inconsiderable progress against the stream, without the aid of trackers. The trackers to each barge, it appears, were generally about 15 men, relieved alternately. In some parts of the river Chen-tang-chiang, the peasants were employed to deepen a channel through the shoals, although the barges drew less than a foot water, which is not unusual in European rivers in dry seasons.

" In almost all the rivers, as they descended to deeper water, they changed from these light barges to junks, which also navigated the Grand Canal; and when they ascended the rivers to where they became shallow, they again quitted the junks for light barges, which latter they used throughout their navigation of the Chen-tang-Chiang, the whole course of which, above Han-choo-foo, where they embarked upon it, does not exceed 200 miles. These junks contained two tier or ranges of apartments, were consequently heavier, and drew more water; but it does not appear they used more trackers to them than 18 or 20; whence it follows, that these rivers have, fortunately for the Chinese, but moderate falls. It has, indeed, appeared to the embassy, that the river Kan-kiang* has an average fall of 20 feet per mile, which is very far beyond what it can possibly have, according to the circumstances of its navigation. With those not actually experienced in improving the navigation of rivers, such an opinion was not unlikely to take place, and no way lessens the general merit of the information on this subject, which appears to be collected with attention, and is diffusely scattered through various parts of the work."

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* " The Yang-tse-kiang, (called. by abbreviation, the Kiang) below the lake Poyang to the sea, a distance of 500 miles, is supposed, by Sir George Staunton, to have 1000 feet fall. This river, where entered and left by the canal, was about two miles wide, with current not exceeding two miles an hour in the strongest part; and much deeper than the Yellow River, which was not more than 9 or 10 feet deep in the middle of its stream."

Of Weirs and Sluices.—When the ascent to be overcome is greater, or the quantity of water which may be spared too small for the navigation in the open river, according to the above described modes, recourse is had to weirs for penning up the water below the fall or shallow, until it attain the level of the higher and navigable part of the river. In this way the successive weirs, already built on many of the rivers of Europe, for the use of mills, have been found to give a navigable depth in cases where it would not have existed, and the only difficulty was, to find a convenient mode of passing them.

For this purpose an opening is made in the weir, which may at pleasure be closed by a flood-gate, and the vessel which has to ascend, being first brought through the opening into the mill pond, will, after the gates are shut, rise with the accumulating water, and where that has attained a sufficient depth, she may proceed on her voyage. She will commonly be stopped at the shoals below the next weir, but when the sluices there are drawn, the flash of water will admit her to go over these shoals, and through the opening of that weir, and so on successively.

These flood-gates, or sluices, are supposed to have been invented by the Egyptians, after the time of Alexander, and at a later period by the Chinese, by whom they are employed, as already described, on their Grand Canal. They were also known to the later Romans, and are still in use in various rivers of Britain and the continent.

They commonly consist of two abutments of stone, one projecting from each bank, with a space between wide enough for the passage of a vessel. This space is shut occasionally by timber let down into grooves, which may be raised or placed singly without much difficulty; or, if one beam be placed across at top, and a sufficient sill at bottom, the planks are placed upright, so as to bear against the cross-beams. To open this kind of sluice, the lock-keepers place themselves on the cross-beam, and take up, one after another, the paddles or planks, not without a great deal of trouble and danger; for, frequently, when the plank has been cleared of the lower sill, the current carries it away, with such force, as not unfrequently to pitch the lock-keeper into the water. After all of them are taken up, the beam is removed, the water speedily lowers, and the boat is hauled up; or, if going down, may shoot through with the stream, the fall never exceeding three feet. When the boats have passed, the beam is replaced, and the paddles fitted up again, one after another. Many improvements have been made on the simplest form of sluices, which still may be seen on various parts of the Thames and Lea.

Where made with gates opening against the stream, as in some of the earlier attempts at inland navigation on the rivers of Ireland, in the middle of the last century, or with great "vannes," lifting by a windlass, as in some of those of the Low Countries, their use becomes very difficult; but were a well contrived stop made, which would readily admit of opening and shutting, its cheapness and conveniency, on many great rivers, would frequently make it be preferred to the more perfect invention of the lock.

In the *Machines Approuvées* three or four modes of working such sluices in a river channel may be seen, worthy of notice from their ingenuity, though we have not heard of any of them being put in practice. More lately, the intelligent engineer Blanken, of Amsterdam, has proposed a mode of making a balance lock-gate applicable to such a case, and actually, we believe, executed for the "Overlaat," or set-off lock, at Woerden on the Waal. The utility of the invention has been disputed by his countryman Goudriaan, from his difficulty of preserving such a lock water-tight. But in countries where water is abundant, this objection is of little moment.

In the sluice gates, or "Pertuis," employed by Mr. Tresaguet, on the river Charente, the lower beam of each gate, instead of being precisely at the foot of the gate, is placed six inches higher than the extremity of the head and heel posts, so as to leave an opening below. The upper part of these gates, from the middle beam to the top, is planked over in the common way. The lower part remains an open frame, which may be closed by means of two paddles or sluices, fitted with racks for raising and lowering them. The paddles being lowered, will descend to the floor of the upper side of the sill, which will be three inches lower than the surface of the floor on the lower side, so as to form a rabbet against which they may bear, to shut the lock more exactly. This rabbet is not necessary to support them, because they have, besides, a bearing at six inches higher against the bottom cross-beam. The uprights of each gate, viz. the head post and middle post, rest against squared stones fixed in the sill of the gate.

To open the gates, we begin by raising the four paddles as far as the lower cross-piece only; and the water escaping below that, will scour away any stuff that may have been deposited at the foot of the gate. When the upper floor has thus been washed, the paddles are raised as far as the middle beam, which is placed nearly at the height which the water would have if there was no sluice. The water will then pass quickly off, and descend to a proper level for navigation, viz. four feet above the sill. The close part of the gate being then all, or nearly all, above water, there is no difficulty in opening the gate, by means of the cross-bar or lever on each side, and then the inconveniency of the pressure of the water, and the depositions of sand, &c. which render it nearly impracticable to work ordinary gates in this situation, are done away.

In passing the falls at river sluices, there is considerable risk of injury to the vessels, since there is a moment when the half of the barge extending beyond the fall, so to speak, hangs in the air, and runs the risk of breaking, or at least straining her considerably below the sluice, the water being obliged to pass between these side walls, and prevented from flowing away laterally, will assume the form of an inclined plane, down which the barge may slide with safety, and up which it may be brought with considerably more ease than when left to assume the form of a cascade. As a general rule, we may say, that the side walls should have one foot length for every inch of height in the fall. A wooden floor should also be laid between these side walls, to prevent the gullying out of the foundation, and the formation thereby of sands and shoals in the channel below the sluice.

The construction of the weir itself requires some particular precautions, and will depend very much upon the materials which are afforded by the country. It is necessary to prevent not only the action of the falling water from loosening the foot of the weir, and, consequently, to render its fall as gradual and gentle as possible, but also to prevent the hydrostatical pressure of the water, when penned up, from forcing a way under the foundation of the wear, and destroying the work. It is also necessary to take care, that the water way over the surface of the wear should be sufficiently large in time of floods to permit the evacuation of the river. It is therefore best to have the dams constructed in the wide part of the river, and formed obliquely to the stream.

Thus, suppose the common width of the river to be 100 feet, and the wears to be made 200 feet long, and to rise 4 feet. In the first place it is self-evident, that those wears would not raise the waters below them. Now let us suppose the water to increase four feet above its ordinary height, 4 feet multiplied by 100 feet will produce a section of 400 square feet; but 200 feet, the length of the wear, multiplied by 2 feet in depth, will give an equal section. This is more than the rise would be upon the wear, because the water running over it would have a greater velocity; but putting that out of the question, the fall over the wear would now be but 2 feet. Suppose a rise of 4 feet more in the common parts of the river, and yet the water would be more than 4 feet below the bank, this would produce a section of 800 square feet; but 4 feet multiplied by 200 will produce an equal section. Now the rise of 8 feet in the common parts of the river is equal to 4 feet over the wear, added to 4 feet the height of the water; so that the surface of the river would now be nearly level; and when this happens, the wear can have no effect in impeding the water, and if the wears were then to be annihilated, no sensible change would take place during the height of the water.

When the wear can be founded on rock, the best way will be to bore holes in the firm foundation, and affix piles therein, which may be then connected with stout planks. Such holes may now be bored, even in deep water, with comparative ease by means of the diving bell; but, in general, it will not be difficult, even when impracticable or inconvenient to lay the bottom dry, to establish a frame or scaffolding to carry upright boring rods, by which such holes may be executed of any dimensions. For a case of this kind, see the article Bridge. When the planking is laid with a slope up the stream, the water rising against will keep it the whole dam down by hydrostatical pressure, although specifically lighter than water; and in this way Leupold proposes to form a timber wear even where it is impossible to attach it to the rock. A very fine specimen of this kind was executed at the construction of the docks of Carlscrona in Sweden. But, in general, it is necessary to give the dam a sufficient mass or weight, to enable it to resist the horizontal pressure of the water. We shall not now enter into this subject, which has been treated of at considerable length by Bossut, Vallet, and others, (see also our article Hydrodynamics,) but shall proceed with details of the practical modes of construction. Where the bottom of the river is soft, or composed of loose gravel or sand, piling becomes absolutely necessary. For this purpose strong piles are driven at regular distances across the bed, the heads sawn off as close as possible, and connected by a beam, which serves to guide a row of pile planks driven between the interstices of the other piles, so as to form a continuous partition across the bed, and as far below as may be thought advisable. Behind these a dyke of rubble stone is formed across the river, and it is usual to insert in this dyke triangular frames, the upper end of which rest on, and are attached to the bottom piles and gauging beam aforesaid. The upper edge or face of this dyke is then faced up with hewn stones or planks, and the interstices of the dry stone work during its construction ought to be carefully packed with heath and gravel. Soft earth mingled with gravel is then applied to the upper side of the dam, and if possible, by dredging in the bottom, ought to be carried some way below the bed of the river, and also some way above the dam to increase the difficulties of transpiration. In the northern countries peat moss is used for this purpose. This puddling or lining, as it is called, is then covered over with a sheeting of gravel or stone, to prevent its being washed away. The lower side of the wear is also to be covered over carefully with a facing of timber, or close pavement, descending by a very gentle plane to the bed of the river below, and the foot of it must be secured by piles or planking as before described. Beyond which a mass of rubble stone may be thrown into the bed of the river, to prevent the scouring effects of the cascade.

In the timber countries, floors of planks are made use of instead of the stone pavement above referred to, and the water is permitted to fall from one of these to the other, until its perpendicular force is destroyed. The framing below these floors is filled with strong puddle, dams of earth, and stone cut off by successive partitions of timber; and instead of the rubble applied to the skift or tail of the dam, the bottom is defended by coverings of fascine work, or brushwood well wattled and bound together, and fixed down with stakes for a considerable space below. In France, and other countries on the continent, where much small wood must be preserved for fuel, this kind of material is very abundant, and is exclusively employed in river works in preference to stone. In Holland, which is destitute of stone, large tracks of brushwood are cultivated on the banks of the canal and other such works, for the sole purpose of being used in hydraulic architecture. Plate CCCCVI. Fig. 1. exhibits the section of a stone wear, constructed by Mr. John Smeaton on the Carron river. Fig. 2. exhibits the structure of a wooden wear with sluices, adopted in Russia on the river Wittogra. By means of these sluices, the water in the river can always be kept at the proper height for navigation, whether in dry weather or in flood, over the shallows in the river. Several wears, with openings to answer this purpose, have lately been constructed upon the Thames, one of which, near Windsor, has been given by Zachary Allnutt, superintendant on the Thames navigation, in his considerations on the best mode of improving that river. It consists of several strong piles or posts, driven firmly into the bed of the river at 20 to 25 feet apart in a straight line across the river. The intervals between these piles are driven, and nicely filled up, with pug piles or dovetail piles as above described. These last are afterwards sawed off straight and even with the bottom of the river, and have a strong and sound sill nicely fitted and spiked on to them, and into each of the large piles at its end. By this means the water is prevented from soaking or making its way, except through the rectangular openings between the several piles, which should be at least as high as the highest floods, and have their tops connected by strong cross pieces of timber bolted on to them. In these cross pieces, and in the sill below, a number of holes are prepared for placing, at equal intervals, as many upright pieces of wood called rimers, with rebates in their sides, for temporary gates to slide down in, and rest against. After these rimers are put in, a sluice or gate, with a tall handle to rest against the upper or cross piece, is put in between each rimer; and above these another set of gates, called overfalls, with similar handles, are fitted, to be occasionally used in dry seasons, when none of the water is to be suffered to escape except by the side cut and lock paddles. In time of flood all these gates, overfalls, and rimers are taken away by persons who go in a boat for that purpose: which operation, we are told, can be performed in three hours, and the water is suffered to take its free course through the openings. As the water subsides, a few of these gates are put in at a time, leaving the water its course through the others until all of them are in, when, on any small rise of the water, the same falls over the tops of these gates into the bed of the river below. When a greater depth of water is wanted above, the overfalls, or upper gates, are successively put in upon the others, these last being of such a height, that the water can fall over their tops before it would overflow the meadows, in case of its rising, and the men not attending, or being expeditious enough in taking away the overfalls, and then the gates, if the progressive rise in the river should render it necessary.

Of inclined Planes and rolling Bridges.—The only other mode employed, before the invention of locks, for transferring a boat from any navigable pond to another across a wear or the like, was, to haul her out of the water up a sloping way to the intervening ridge, and launch her from thence into the other canal. The Chinese have proceeded no farther than this in their system of inland navigation; and the following account of their practice, extracted by Mr. Chapman, may not be foreign to our present purpose.

The "inclined planes" of the Chinese "are particularly described in the route from Hang-choo-foo to Tchusan, which was pursued by Colonel Benson and Captain Mackintosh of the Hindostan, after they had parted with Lord Macartney, and the remaining attendants of the embassy, who followed the route already described to Canton.

"The Tchusan party crossed the river, and entered a small canal. After they proceeded about three days, they arrived at the city of Loo-chung, where they changed their inland barges for junks of about 60 tons burthen each, neatly fitted up for passengers, but constructed for salt-water navigation, and lying on a river into which the tide flowed beyond Loo-chung. They sailed from thence to Nimpo, near Tchusan; the river was of the breadth of the Thames between London and Woolwich.

"Before their arrival at Loo-chung, it sometimes happened in the route to Tchusan, that the water of a higher canal passed immediately into another of a lower level; and in two instances the travellers were launched in their barges with prodigious velocity down the stream.* The upper canal is bounded by a strong and well compacted wall, the top of which is level with the surface of the upper water. A beam of wood is laid on the upper edge of the wall, which is rounded off towards the water. Beyond (or below) the wall, a sloping plane of stone work extends to the lower canal in the form of a glacis, with an inclination of about 45°, and descending near 10 feet in perpendicular depth, at the bottom of which the canal is carried along as the level of the country will allow, when another wall and glacis for another canal still lower are constructed as before.

"In passing from an upper to a lower canal, the vessel tilted over the cross beam slides down by its own gravity, and to prevent the water from flushing over the decks, or her plunging into the canal below, a railing is fixed at the head of the vessel about to be launched, before which is placed a strong matting at the time of its descent. To draw up a large vessel from the lower canal along the glacis into the upper canal, requires sometimes the assistance of near a hundred men, whose strength is applied by means of bars fixed in one or more capstans, placed on the abutments on each side of the glacis. Round the capstans is a rope, of which the opposite extremity is passed round the vessel's stern, which is thus conveyed into the upper canal with much less delay than can be done by locks, but by the exertion of much more human force,—a force, indeed, which in China is always ready, of little cost, and constantly preferred there to any other."

"This description of the Chinese inclined planes appears to be correct in the outline, but cannot be taken literally, as 45° declivity is far too steep, unless the fall be so little as to bear a small proportion to the length of the boat; and then the steep inclination of the plane would be of little moment, as the boat need never touch it but on sliding off with its heel.

"In the plate the description is partly corrected, as the inclination is but 14° from the horizon, viz. one foot fall for every four feet base, which is also too steep, unless the boats that pass these planes be much shorter than the general run of their boats; which is the more probable, as otherwise they would strain and break in two with any lading on turning over the cross timber at the head of the plane. These boats, according to the plate of the inclined plane, are of about 3 feet height, and 56 feet tread on the ground, with sharp overhanging ends projecting 9 or 10 feet, and rising with a bend equal to the descent of the plane, therefore tending at one end to raise the vessel in its descent, and at the other to produce the same effect, in a small degree, by the weight of the boat's end behind the tread of her keel. I shall assume the boat to be so far laden, as to have as much buoyancy above as below water, and the effect of the projecting ends to be under that predicament, equivalent to a shortening of it to 8 feet less than its tread on the ground, viz. to make it equal to a boat of similar section from end to end of only 48 feet, in place of 75 feet in extreme length. From these premises, and admitting the transverse section to be square, which will not materially alter the case, (as their section, exclusive of the ends, is uniform,) we may deduce what the floating power of such a boat would be.

Under this predicament, it is obvious that a diagonal line from the summit of one end of the boat to the lower extremity of the other end, would divide its bulk into equal parts, one of which, immersed in water, would be just equal to its whole weight; therefore, as under the given angle of inclination and weight of boat, the water would only flow 12 feet along the boat's bottom, or $\frac{1}{4}$ of its length, it follows that, at the instant of immersing one end under water, it would only have $\frac{1}{4}$ of its weight water-borne. The centre of gravity of this tendency to lift the boat, would be at 4 feet inwards from its lower extremity, viz. at $\frac{11}{12}$ of the distance from the boat's keel, which latter would be its turning point. It is evident, that a power equal to half the weight of the boat and cargo, applied at its lower extremity, would enable the boat to rise, as the other extremity would bear half the weight;* but, in the present instance, there is only half the necessary power acting at $\frac{11}{12}$ of the requisite arm of the lever, consequently, only equal to $\frac{11}{24}$ of the requisite force; therefore, with the aid of matts, towards the head of the boat still unequal to the end.† If, however, we combine the description of the fall, viz. 'near 10 feet in perpendicular depth,' with the length of the plane, in the plans accompanying the work (which the eye might judge of, comparatively with the length of the boat) we shall have a declivity of about $\frac{1}{6}$, or nearly 9½ from the horizontal line, which will pretty well accord with the circumstances."

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* "It appears from this description, that water was running down the inclined planes; and if so, it is accordant with some of the descriptions of the Jesuit missionaries. This, however, is probably only occasional, and caused by the fluctuation of the surface of the canal."

"I can easily conceive, that the travellers might be mistaken in the declivity of the plane, if they judged by the eye, as angles of ascent and descent are very deceitful in their appearance. That the boats are longer than on reflection we should conceive them to be, appears corroborated by a traveller of the last century, Father le Compte, who observes, that 'in some places, where the disposition of the ground does not permit the forming of a communication between two canals, they still contrive to pass vessels from one to the other, notwithstanding they have more than 15 feet height to surmount. At the extremity of the upper canal, they construct a double glacis, or inclined plane, of hewn stone. When a vessel arrives at the extremity of the lower canal, it is raised by the help of capstans to the summit of the first glacis, from whence its own weight makes it slide on the second into the upper canal, and they descend to the lower by reversing the operations."

"This author could scarcely comprehend how the Chinese barges, which are commonly very long and very heavy laden, did not break in the middle when suspended in the air, on the angle, between the double glaces; nevertheless, he did not learn that the least accident ever happened. 'These inclined planes,' he says, 'are not to be found in the grand canal, because the imperial barks could neither be raised by manual force, nor secured from the misfortune to which the others have the appearance of being liable."

"In the journey of the Fathers Boures, Fontenay, Le Compte, &c. from the port of Ningpo, they relate that they soon 'came to a place where they hoist up the barks, in order to convey them to a canal which is 9 or 10 feet higher than the level of the river. They hoist up the bark by means of a slope or declivity, paved with large stones, and when they have got it to the top, they let it slide down another into the canal.' "There are people who wait to be hired for this purpose; they are not above a quarter of an hour about it, having the help of two capstans."

"This inclined plane is, in the same district, described by the Tchee-san traveller, (probably one of those they descended.) and differs in nothing but the time of passage, which will depend much on the force employed. If the aid of capstans be used, in which both narrators agree, the passage cannot be so quick as by a well-regulated lock. Their account of the Kiang and Yellow rivers, and of the canal, in their route to Pekin, considerably resembles Sir George Staunton's. Some of the sluices or flood-gates upon the great canals, are described as retaining the water in confined channels of masonry, (apparently of some extent,) through which it rushes with vast impetuosity, so as to require great power of capstans and of men, to get the vessels up; and that, in place of letting them run down at will, they are carefully let through by ropes that are slacked away, until they are below the strength of the stream."

Inclined planes similar to those in China, under the name of *rolling bridges*, have long been known in Europe, particularly in Holland and Italy. The object seems to have been, not so much to overcome a difference of level, as to prevent the transference of water from one tract of country to another, on account of the jealousy of drainage. One of the most remarkable of this kind is the *Overtoon*, between Amsterdam and the Haerlem Meer, already noticed under Holland, and which is preferred, on account of the interest which the city of Haerlam has, in continuing the ship navigation through the ancient sea sluices of Sparendam. At Lizzafusina, near Venice, is an ancient machine of the same kind. The fresh water of the Brenta is, in this place, prevented from flowing directly into the lagoons of Venice, which had been thought the cause, not only of the unwholesomeness of these lagoons, but also of their rapidly filling up, and thereby endangering the security as well as the navigation of the city. New channels were, therefore, cut by the state, for this and other rivers, in order to lead them to more distant mouths; but the old bed is still employed for the purpose of navigation, and forms the direct track from Padua to the city of Venice. The vessels are transported over the wears by means of two strong sledges, fitted with trucks, travelling upon railways, and drawn by a rope passing over an axle, which is worked by a horse whim. The following figure and description of the machine is from Leupold. (Pl. CCCCVII. Fig. 1.) "The carriage is made of square balks, of which the two long ones have, at each end, iron rings, PQ., to admit the hooks of the cable. The other two balks are shorter, and connect the long ones in a square form. Within these are two other balks, RS., the same length as the cross ones, and all well jointed together. In this square frame are four rollers, each one foot in diameter, and 9 inches broad, strongly hooped with iron. The remainder of the machine lies upon the ground. These carriages slide up and down into the water, alternately. Hard by is an upright shaft, with a pinion at the head, and with two cross bars, to which horses can be attached. The pinion works into a face wheel, on the horizontal axle of which a rope is wound, fitted with iron hooks at the extremity, which are attached to the ship and carriage, and by this means draw them over the bridge. Here it is to be remarked, that the horse which walks on the right side, takes the ship which is given to the sea, and the horse which is on the left side, takes that which is given to the river or canal. Between the river, or Brenta, and the sea, or salt lagoons, the dyke or bank, where the carriages pass, is built of masonry, with a rope over it. There are also two stone ledges, between which the rollers go, and of the same breadth as the rollers. The extremities of those ledges, on both sides, are firmly constructed with a pavement of large and hard stones, so that they may not be shifted by the traversing of the carriages. Other particulars may be discovered in the plan."

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* "Nearly so, the turning point being only thrown backward the tangent of the $\angle$ of inclination upon one-third of the boat's height. To make the other deductions perfectly true, the centre of gravity of the boat and cargo must lie at one-third of its height; and if higher, as it generally must be, it will operate against the power of the boat's rising"

† "Unless these were at the bottom of the glacis, an apron, or smooth platform, at such a depth as not to admit the boats to sink, which does not appear to be the case, nor could well be so, under such fluctuation of surface as the canals are liable to.

This structure may, in all probability, be considered as the parent of all our modern inclined planes, as the pertuis has been of the modern lock. Meyer, and other German writers, seem to have thought very highly of the rolling bridge, or inclined plane, and recommend it strenuously when the river navigation is obstructed by rocks or steep hills; but we do not know of its having been brought into use for high lifts, before it was adopted, in 1788, by Reynolds, and others, on the banks of the Severn, although Mr. Dukart, who had been an engineer in the Sardinian service, and may probably have seen this in Italy, attempted to introduce it in Ireland, at the Dungannon Collieries, as we have described when speaking of that country.

"These collieries," we are informed by Mr. Chapman, "are less than a mile north of Dungannon, and about three miles from the colliery basin, at the head of a canal, ascending by eight locks from the river Blackwater, near its junction with Lough Neagh. The rise from the basin to the colliery was little short of 200 feet; and after attempting, very improperly for the particular instance, to conquer this great ascent in that short space, by continuing the lock navigation, and finding the sums granted by government for that purpose inadequate to the design, he turned his attention to small boats and inclined planes, of which he constructed three, connected by narrow canals. The falls were seventy, sixty, and fifty-five feet, which last terminated about 15 feet above the colliery basin; from which, by a short rail-way, his boats, again floating over a carriage, were drawn onward to the wharf, where the rail-way was supported on yeers, or frames, and the boats were turned over to discharge their cargoes.—They were calculated to carry, each, a ton of the measure the coals were sold by, viz. (about 27 cwt.) which they did, at less than 18 inches draught, so that his canal might be every where fordable; and accordingly no bridges were erected upon it.

"The boats were flat-bottomed, and upright at the sides and ends; their width was 4½ feet, their height 2 feet 6 inches, and 10 feet straight side; one end was square, and the other pointed, so as to form a right angle at the stern; and they went, as in all similar cases, a number of them chained after each other.

"His first attempt differed from the 'Ponteaux Rouleaux,' in no other respect than having a double passage down his inclined planes; so that, by means of a rope leading over a wheel, his loaded boats drew up his light ones; but, finding various inconveniences from some of the rollers not turning, and from the individual inequality of the diameters of others throwing his boats to one side, as well as from other causes, he suggested, and put in use, the method now practised on the banks of the Severn, of having a cradle or frame, with four wheels, brought under his boats, upon which, over a double rail-way, they alternately ascended. The sole difference between the two methods being in the size of his boats, and that, in place of a steam-engine, he made use of a horse-gin to draw his boats, upon the ridge terminating the upper level."

"This work was executed a little prior to the year 1777; but, excepting passing a few boats by way of trial, nothing more was done, as Mr. Dukart could not obtain money to complete some of his intervening levels, and died soon after the time mentioned."

The following letter from Mr. Smeaton shows, that that engineer, as well as Mr. Jessop, were acquainted with this scheme, and had been consulted respecting its practicability.

Brough, 30 *April*, 1774.

To Mr. Jessop.

My journey into Yorkshire gave me an opportunity of reading and considering your report, by way of representation of the several matters relative to the works of the Tyrone canal; and, having been at home but one day, I now take the opportunity of a leisure hour, to give you my opinion thereupon, so far as I can do it without entering into calculation.

Had this canal been unbegun, the circumstances attending it are such, that I never could have recommended a canal of any kind, as I am sensible it never could be made in any degree to answer the expense. But, if I understand you right, the bulk and expense of the work is, in a great measure, incurred, there being little to do but complete the inclined planes between the different reaches of the canal. I think, therefore, that it would be a great pity, after the public has been at so considerable an expense in constructing the apparatus, but that the experiment was made, and the validity of this mode of navigation put to a thorough proof, especially as it may be a meet point, whether it may be cheaper to navigate upon this canal, supposing it ready made, and given for nothing; or, to begin a new work; which, at any rate, will cost a considerable sum; for, by this means, the public will, at least, be put into possession of this piece of knowledge, *i. e.* how far a scheme of this nature is likely to answer in other places.

I think the best chance of its succeeding will be obliging the loaded boats going down to draw up the empty ones returning, which may be done by a simple pully, with a brake or convoy upon it, to moderate the velocity of the descending boat; and that a great deal of friction may not be wanted upon the pulley, as you say the plane rises one in five, I fancy they will act very sufficiently, if they are made to slide upon the solid, rather than upon rollers; but I fancy that light wooden rollers will be wanted, at proper distances, to keep the ropes from rubbing upon the gravel, or solids between the slides; and as I do not apprehend that above one boat can be let down at a time, for greater despatch, I think it will be better to make the boats carry two tons rather than one, by making them of double length. I do not, however, hint these things by way of adopting the scheme, nor can I answer whether it will do or not; but, as matters are carried on to so great a length, by way of suggesting the likeliest means of getting an effectual trial of Mr. Dukart's scheme.

If this scheme does not, on trial, answer, I am of opinion that a rail-road of wood, in the manner of those at Newcastle and Whitehaven, is much to be preferred, in such a situation, to either a canal or a gravelly road, especially as you say it can be done with a length of two miles, and all, or most of the way, down hill. This being the case, the waggons will go down loaded, by their own gravity, and the horses will have nothing to do but to draw them empty back again, which, in a rise of 192 feet in two miles, will be easy work.

Rail-roads of this kind are, in common situations, executed in the neighbourhood of Newcastle, so as to carry coals at the rate of 2d. per neat ton per mile, the original charge of making, maintenance,—of wear and tear of the roads—waggons, horses, and drivers included. But as the cheapness of things greatly depends upon a country's being used to the execution, which can never be the case in the first instances, if we suppose 6d. per ton per mile, of the Tyrone tons, they will be more than can be done upon the canal, after the whole of the original expense has been given.

You will be pleased to communicate my sentiments to my Lord Archbishop of Armagh, with my most dutiful respects, and am,

Sir,
Your most humble servant,
J. Smeaton.

P. S. I apprehend it will be necessary, besides a simple pulley for returning the rope, to have something of a tackle assisted by a winch or windlass, by way of bringing the boats upon the inclined plane, and till they are launched upon the down going side.

Of Locks.—The discovery of the lock, an invention altogether modern, simple as it appears, has given an entire new feature to the inland navigation of Europe. It has enabled this art to continue the convenience of water carriage over districts formerly impracticable, not only along the valleys, but across rivers and mountains.

We have been at some pains to trace the original discoverers of this important engine; and though our researches have not yet been attended with all the success we could wish, yet we have been enabled to acquire some new lights respecting the early history of an invention, which three centuries, perhaps four centuries, have not yet brought to its ultimate perfection. Belidor, in his *Architecture Hydraulique*, supposes the invention to belong to the Dutch, from some expressions used by Stevinus, an eminent engineer of that country, in his treatise *Sur la nouvelle Maniere de Fortification par Ecluses*, published in 1634; but that superficial inquirer does not seem to have comprehended the particular invention which Stevinus describes, who expressly says, that locks of the modern construction, a figure and very correct explanation of one which he gives, had been known in Holland from very early times. His object was to describe a new kind of sea-lock then lately invented, for the purpose of securing the harbours, and which might at the same time admit the passage of masted vessels. The difficulty was, to form gates which could be opened when the water on their two sides was at different levels. The inventions of several engineers there mentioned are described, and the preference given to the plan of turning gates, placed so as to fill up the frame of the common gates, and which, when let go, fall into the line of the stream.

Stevinus first gives an account of the common mode of effecting the first object, as had been in use for a long time, viz. the raising a common sluice door by a windlass, which, he says, does not allow the passage of masted vessels.

2. He describes the sluices used for draining low lands, consisting of two doors butting against the tide, and shutting of themselves, which, he says, are more useful than raising the sluices, because they admit of being larger, and require no attention to watch the tide; but he says they also are defective in not admitting masted vessels when they are placed under the dyke, and in not retaining water to scour the channel.

3. The third kind of sluices, serving to pass masted vessels, are made with two pair of pointed doors, like the second, but raised as high as the dykes themselves, comprising between them a receptacle for ships, with two small sluices made in the walls, or in the doors themselves. Then he describes briefly the mode of passing a ship through the locks.

Besides these, he says others have been made which open of themselves, with the ebb falling on the bed, and rise with the flood; also gates which are drawn aside into the land. but their use is not convenient.

Stevin also informs us, that he and several other engineers had agreed to study this subject, and communicate their inventions to each other. The following was the result.

Adrian Janssen, carpenter of Rotterdam, invented the locket for holding a turning gate in its place. A turning gate had been made at Briel, which was retained in a groove at the bottom, out of which it was wound three inches by a rack ere it could turn into the line of the stream.

Stevins' mode was to have rising vannes the whole width of each butting lock-gate; Cornelius Dirricksen Muys of Delft, to have second lock-gates holding up the first; and Adrian Dirricksen of Delft improved Janssen's mode, by applying them in folding gates. He got a patent for it from the state, and built two at Maeslandsluis and two at Helvoetsluis of that kind, which yet exist. Stevins' whole account of this mode of scouring harbours is well worthy of attention.

Of the Italian authors, the first who enters into the history of the discovery is Zendrini, in his treatise *Della Acque Corrente*, published in Venice 1746, who says, that being interested in ascertaining the original inventors of locks, he had taken some pains to search the Venetian annals on the subject, and found that the first lock was invented at Stra, near Viterbo, by two brothers of the name of Dominico, clock-makers in Viterbo, who had a patent for its construction from the senate of Venice, in the year 1481. The patent describes, that these engineers had engaged to construct a sluice, (concha,) in which boats might pass without danger, and which being so contrived, that the water passing out with facility, the vessels would neither be required to be discharged nor drawn over. This account has been acquiesced in by Lalande and other writers; but Lecchi, in his book *Dei Cannali Navigabili*, alleges that, previous to this period, in 1420, the lock had already been introduced in the navigation of Milan by Fillippo Maria Visconti, as mentioned in his life by Decembrio, one of his courtiers. And in 1188, Petentino, the architect of Mantua, had thought of it in his dykes on the Mincio, at Governolo, the first attempt at overcoming the fall of rivers in all Italy; so that Lecchi claims it for Lombardy. Nevertheless, there is every reason to believe that these cases were nothing more than the wear and single flood-gates already used for the navigation of rivers; for Bertazzolo, in his discourse upon the sluice of Governolo, published at Mantua 1609, proposes a lock with a chamber, (sostegno,) to be built at the sluice of Governolo as a new thing. This lock has since been established on the left bank of the Mincio; and, connected with an opening wear, it serves to hinder the turbid waters of the Po from filling up the lower lake of Mantua, while at the same time it preserves the navigation. Indeed, in many parts of Lombardy, wears with flood-gates are yet employed for river navigation, although locks exist of an early date, and some of them also of singular magnitude and boldness. To conclude, we may observe, that, at all events, a very few years after the supposed invention in the Venetian state, the celebrated painter, architect, and engineer, Leonardo da Vinci, in 1497, applied locks to connect the Milanese canals derived from the Adda and the Tesino.

We must next consider the claims of Holland, that other great cradle of the hydraulic art of Europe. We have formerly noticed, that the embankment of the different districts of Holland had chiefly taken place between the years 1000 and 1400. In 1253, a placart was granted by William, Earl of Holland, to the city of Haerlem for the construction of the sluices of Sparendam. Those sluices must have necessarily been a lock; for it is expressly said to be constructed for the more convenient passage of ships, and a toll is appointed to be collected on the vessels which make use of it.

About the same time, viz. 1255, the jurisdiction of Delftland was established, and the ancient canal from thence to Leyden completed. On this canal, at the separation between Delftland and Rhineland, is the basin of Leidsendam, which, as we have already observed, becomes, to all intents and purposes, a complete lock, by means of the stop-gates belonging to the two jurisdictions at either end, and it has always been used as such.

At the same period, the citizens of Utrecht had formed an aqueduct from the river Lech at Vreeswyck; and in 1371, as we are informed by Hada, in the history of Utrecht, they deepened and enlarged this aqueduct, so as to make it navigable, and placed at the bank of the river Lech double flood-gates, or stop-gates of timber, by which the waters might be more easily kept out or introduced. (Hedæ *Hist. Epist. Ultraj.* Arnold. ii. *Episc.*) This structure was certainly a lock, as we see by the note upon the passage, describing an improvement which was made within the same century by the addition of a third gate, thereby converting it into a double lock. From this note, it is evident that the original structure permitted the passage of vessels, which William only rendered *more secure* during the high floods of the lock, by the construction of the third gate on the side next that river, thereby forming two chambers instead of one; and by the care that is taken to mention the name of this artist, it appears that the original or single lock was not considered as any new invention. There is, therefore, strong reason to believe that in Holland the lock was known, and in use at least a century before its application in Italy.

OF CANALS, OR STILL WATER NAVIGATION.

General Observations.

The navigation of rivers is a natural and obvious resource, and occurs to a certain extent in the rudest state of society; but the formation of artificial canals requires the well-combined labour, and the persevering efforts, of many individuals, well instructed in various arts. It therefore can only be effected in a comparatively refined age, when population has become dense, and their political organization more complete.

Though certain states of Asia, Egypt, &c. appear to have arisen on the banks of the great rivers, and must therefore have been well acquainted with the benefits of navigable communications, it would appear that drainage, rather than navigation, was the original object of their hydraulic works, and that the latter only was attended to as a collateral advantage. The same may be observed of the European states, and all those parts of the Roman empire, in which hydraulic works attracted the attention of that active and enterprising people. The flat lands, as the mouth of the Po, the Rhone, the Rhine, on the Continent, and the forelands between the Humber and the Ouse in England, are the cradles of hydraulic science; for there necessity had stimulated the inhabitants to unite in defending themselves from, and at length to subjugate and guide, the waters which surrounded them.

In such countries, the formation of canals is comparatively simple. It consists merely of excavation; the flatness of the country exhibits no oblique inclinations to the course of the canal, and little variety in the nature of the soil, so that there is seldom any reason for departing from the straight line, or overcoming any sudden depression; accordingly, here, canals chiefly consist of a series of straight cuts from one pond or pool to another, ramifying through a considerable area of country upon one level. When there is any opposition of interests among the inhabitants, they carefully dam out the surrounding waters, and allow a communication between the neighbouring navigations only by transporting the boats over the land, as is still not unusual in Holland and the English fens.

In cases where the tide-waters afford a varying level without the canal, an opportunity of communicating between the navigations exists twice a-day, and a single pair of gates is all that is necessary. Hence, in fen countries, on the ocean, sluices seem to have been known long before the more perfect invention of the lock or sas was thought of.

But in the higher countries, the mode of conquering the ascents and descents was the chief object to be accomplished. The canal is laid out in portions at different levels, each carried along the sloping ground as far as may be convenient, and the connection between them is formed by some of the various modes which have been invented for that purpose.

Of all these modes, that by locks is perhaps the most simple and beautiful. But before we enter upon the theory and properties of the lock, it may be better to explain the mode of laying out the levels of the canal.

Theory of Canal Cutting.

It is evident, that in cutting canals, no farther excavation is required than that which will hold the water, at the given depth and breadth; and since, according to the modern practice, a bank on either side is likewise made with the stuff excavated, it is evident, that if we make that bank of sufficient strength and closeness to contain the water, the level of the surface of the canal may be thereby raised above the natural surface of the land, and great part of the excavation saved. One of the first objects, therefore, in canal cutting, is to know at what height above the surface of the land the canal may be carried on level ground, when the excavated stuff or cutting will just make the banks. This is called level cutting.

When the ground along which the canal is carried has a declivity, the quantity of stuff to be applied to one bank is necessarily greater than that wanted for the other. This disparity may increase until the one bank vanishes, and the canal is cut entirely along the side of the hill, and only the lower bank is required to be made.

This is the simplest case of canal cutting, and the work admits of being laid out in a much more expeditious way than has commonly been employed, as will be seen: this case is called side cutting, or oblique cutting; the slope of the cut which is made in the hill being made the same as the exterior of the canal bank. These two lines in the section are parallel to each other; and there is a certain point in the section, through which, if any line be drawn, representing the surface of the ground in any case, which line we shall call the line of cutting, the portion of the section thereby exhibited as excavation will always be equal to that exhibited as embankment. We shall call this point the centre of cutting.

Problem I.

Given the outline section or profile of a canal in sidelong ground, with parallel slopes. To find the centre of cutting.

Case I. For one bank only.

Given ABCD (Plate ccccviii. Fig. 5.) a section of the canal, CDEGF a section of the bank. To find the centre of cutting,

1 Graphically.

Produce the lines BC and ED to G and A. Draw the perpendiculars Cm. Dn, and the diagonals AG, mn intersecting in p.

Through p draw the parallel spt, and bisect it in o; o is the centre of cutting, through which, if any line HoF be drawn cutting the slopes AB and EG produced, the section $HBCw$ will always be equal to wDEF.

For $mnD = CDn$. therefore, $mnGE = CDEG$. But $mnGE = sBGt = CDEG$; and taking away $CvtG$, we have $sBCv = vDEt$, and the triangle Hso and otF are equal, having equal angles and the side $so = ou$. Wherefore, the sum $Hso + sBCv = otF + vDEt$; and taking away the common part owv, there remains $HBCw = wDEF$. Q.E.D.

Cor. 1. The height o, of the centre of cutting, above the bottom BC, is constant; and it may be found by saying, AE or BG : Gn or Em : : Ax or mC : oz.

That is, As total breadth at top of canal and bank,
To breadth of bank added to base of one slope,
So the depth of canal from surface,
To the depth below centre of cutting.

Cor. 2. The centre of cutting is also the centre of cut and cover, for Ho is always equal to oF. Hence, if a line be staked out along the ground at the level of the centre of cutting, it will exhibit the middle of the ground wanted for the use of the canal, whatever may be the inclination of the surface, at least if that inclination be regular as far as the breadth required; and the distance oH or oF, on each side of the centre, may easily be found by a line drawn across the section with the given inclination of the ground.

Cor. 3. The distance of the centre of cutting. from the centre of the canal at surface water, is constant, and is equal to $uq + DE$.

Hence, if the line of the middle of the cut and cover be laid out, or the centre of cutting, we may lay out a set of stakes at a certain horizontal distance therefrom; and the top of these stakes being made even with the level of surface water, they will exhibit the line of the middle of the canal when finished.

Cor. 4. At half the general breadth AE, from the centre of cutting, and on that level, is a point in the exterior slope of the bank, and a line of stakes may be set out at that distance and level, which will direct the wheeling of stuff for the formation of the bank. And at these stakes a level and plumb line may be applied, with the slope of the bank, by which the point F, where the exterior slope of the bank meets the surface of the land, will be found, and may be marked out, and the edge of excavation will be at an equal distance on the other side of the centre of cutting.

Cor. 5. At the same distance, viz. half the general breadth AE, and on the upper side of the centre of cutting, at its level is the point s, in the inner slope of the excavation.

Cor. 6. The horizontal distance ov, of the inner slope of the bank from the centre o, is constant, and will be found by saying $Dn : nC :: zo : ov$; a line of stakes may therefore be placed at this distance and level, to direct the wheeling, as in Cor. 4. and by a level and plumb, the commencement of the bank and excavation may be marked in the same way.

Cor. 7. The quantity of excavation above the level of the centre of cutting is the triangle osH, and the base os being constant, it will always be proportional to the height Hy of the upper edge above the level aforesaid.

Cor. 8. The quantity of excavation below the level of the centre of cutting is nearly constant, differing from $sBCv$ only by the small triangle owv, of which the base ov being constant, the area is proportional to the perpendicular from w to the level of the centre of cutting.

Case II. When there is a bench or towing path on the upper side, given aABCDEG, (Plate ccccviii. Fig. 6.) as before, the profile of the path, canal, and bank, take $Dd = aA$, draw ab and cd parallel to the slopes, thereby converting the section aABCDE into $abcd$E, in which the bench or towing path is supposed to be added to the bank; proceed with this exactly as in the last case, to draw the lines aG, cd, and st; the middle o will be the centre of cutting.

Cor. 3. In this case, the distance from centre of canal equal $uq + DE - aA$.

Also, $Eq : Em :: \frac{1}{2} mc : oz$
That is, as $aE : ED + Dd + dm :: mc : oz$.

Problem II.

To reduce the section ABCDEF, (Plate ccccviii. Fig. 7.) with a second bench or path EF, to the equivalent section ABIKF, with one bank only, but wider and shallower, the banking cut down and filled into the bottom.

Produce BC and HF to Z, also CD to G; make $DN = DG$. Draw the parallel NL (or, if the slopes are all equal, make DL perpendicular to GC) on FL, describe the semicircle LMF, cutting the perpendicular GM; make ZK (and ZI) equal to ZM; draw the parallel KI, and it is done.

Demonstration: The triangle $NGF = DGFE$, and NLG and CZG are similar; GM is a mean between FG and GL, and $ZK^2 = ZG^2 + GM^2$, wherefore the triangle $IZK = CZG + DGFE$. Q.E.D.

The height of IK over CG is nearly found by the slopes.

PROBLEM III.

Given the profile of a canal with two banks, the slopes being all equal. To find the lines of level cutting.

Reduce the section ABCD (Plate ccccviii. Fig. 8.) into AHKE by the last problem. For this find o, the centre of cutting. Produce each slope to meet in V; draw the perpendiculars VN, ON; with centre N and radius NV cut EA in p; make V a = PQ, and through a parallel to EA draw ML the line of level cutting.

For through o draw the horizontal line $x\,y$, and by the property of the centre of cutting we have s KH v = v AI x. It only remains to be proved, therefore, that sL a M x=LEG. Now, the triangles s E y, LEG, $x\,y$ V, and MVG, are all similar, and therefore as the squares of their perpendiculars.

Therefore, sEy : xVy : : NQ^2 : NV^2, and the difference of xVy and s E y, that is x VE s is to MVG as NV^2 — NQ^2 is to Va^2. But p Q^2 = NV^2 — NQ^2, and is equal to Va^2. By construction, therefore, x VE s = MVG, and taking away the common part MVEL, we have s L a M x = LEG. Q.E D.

By calculation.

Take depth of centre QN = d, $b = \frac{1}{2}$ breadth AQ, and the proportion of the base of slopes to the height as $m : 1$. Then QV = $m \times$ AQ = $m\,b$, and

$$\overline{m\,b \times (m\,b + 2\,d)}\,\Big|^{\frac{1}{2}} = p\text{Q} = \text{V}\,a$$

and V a — VQ = Q a, the depth of level cutting from the top.

COR. It is evident that the quantity of excavation and embankment is a minimum in level cutting.

PROBLEM IV.

Given as in last problem. To find any line of oblique cutting.

Find the line of level cutting. Produce the slopes to meet in V. (Plate ccccviii. Fig. 9.) Draw the perpendicular VI; from L draw LN with the given obliquity or slope of the ground, cutting VI in N, making N p and p Q = VI, also VR = p I. Through R draw KRH for the line of oblique cutting required.

IR or IQ is its height above level cutting, whence o I may be found, &c.

COR. o is not the centre of cut and cover in this case, for since L o is less than o M, G o is less than o K.

By calculation.

Find VI, also NI,

$$\text{Then } \overline{\overline{\text{VI} + \text{IN} \times \text{VI} - \text{IN}}}\,\Big|^{\frac{1}{2}} = p\,\text{I} = \text{VR},$$

$$\text{Or, } \sqrt{\text{VI}^2 - \text{IN}^2} = \text{VR, and VI} - \text{VR} = \text{RI}.$$

Again, as NI : IL : : RI : I o for centre of canal.

If the slopes are parallel, then NR = NI, and I is the centre of cutting, as in the first problem. The centre cutting over level cutting, in this case of oblique shallow cutting, is the difference between $o\;z\;y$ and $o\;t\;u$.

PROBLEM V.

Given the profile of a canal, as in last case, and the line of ground level too low for level cutting. Required to widen the canal so as to have cutting for the banks.

It is obvious that the trapezoid OM (Plate ccccviii. Fig. 10.) must be provided for by the parallelogram DQ, wherefore draw the perpendiculars MN, D p, and make D p = RS. Draw the parallels ON and PQ; DG is the additional width, or CG is the mean bottom.

Or, by calculation, as NT : TO, so pD = R s : DC.

TO is formed from LM by adding the slope base for the height MT at each end, and is usually LM + 3 MT, or 3 RS.

A similar problem to the above may be given for narrowing the canal in deep cutting; but this is of less use; and it is evident that, when the ground OK is at or below the bottom CD, the problem is impossible, and the case becomes one of embankment.

EXAMPLES.

Given a canal of 14 feet bottom, 26 feet water surface, the banks rising two feet over water, and 10 feet broad at top, slopes being $1\frac{1}{2}$ to 1, required the centre of cutting:

26
$\underline{6} = 2 \times 3$
32 breadth at top
$\underline{10}$
42

6 total depth
$\underline{1\frac{1}{2}}$
9 inner slope
$\underline{10}$ top bank
10
$\underline{6}$
42) 60 (= $1\frac{3}{7}$ feet, the height of the centre of cutting over the bottom of the canal.
$\underline{42}$
18
$\frac{18}{42} = \frac{3}{7}$

$\frac{42}{2} = 21$ feet, is its distance from the inner slope of the upper, and from the outer slope of the lower side.

From 6 deduct $1\frac{3}{7}$ and there will remain $4\frac{4}{7}$, which multiplied by $1\frac{1}{2}$ will give $6\frac{6}{7}$, to which add 5, the half breadth of top bank, and the sum $11\frac{6}{7}$ is the distance from the middle of the canal.

$1\frac{3}{7} \times 3 = 4\frac{2}{7}$
$\underline{14}$ bottom,
$18\frac{2}{7}$ breadth of canal at level of centre.
$\underline{21}$ half total breadth ditto.
$2\frac{5}{7}$ distance of centre from outer slope of the canal, and it is evident that the centre of cutting is in the bank in this case.

EXAMPLE.

The Caledonian Canal has 50 feet bottom, and 20 feet water; the slopes are $1\frac{1}{2}$ to 1, to within two feet of surface water, where there is a bench or retreat of five feet; above this the banks rise five feet with a slope of two to one, and are 18 feet wide at top. On the upper side, in side-cutting, there is a bench or towing path of 10 feet.

The area of the part on each side over the bench or retreat, if the inner slope was carried to the top, would be,

$(5 + 7\frac{1}{2}) \times \frac{5}{2} = 31\frac{1}{4}$, and the breadth at top is $7\frac{1}{2}$ feet

$$\frac{31\frac{1}{4}}{23} \times 2 = \frac{62\frac{1}{2}}{23} = 2\tfrac{33}{46}.$$

So that the space contained over these benches is equivalent to widening the canal $2\frac{33}{46}$.

The depth $23 \times 1\frac{1}{2} = 34\frac{1}{2}$, is the base of the inner slope if produced to the level of the top of the banks;

whence $50 + 2 \times 34\frac{1}{2} = 119$, would in that case be the width of the canal.

Also $18 + 7\frac{1}{2} = 25\frac{1}{2}$ would be the breadth at top of the bank, and $10 + 7\frac{1}{2} = 17\frac{1}{2}$ would be the breadth of the upper bank; their sum, 43 feet, must be diminished by $2\frac{33}{46}$, and the width of canal increased by the same quantity, to allow for the recesses at top. Then say, as total width $119 + 43 = 162$ canal and banks to $43 - 2\frac{33}{46} + 34\frac{1}{2} = 74\frac{36}{46}$ top bank and one slope; so depth of canal 23. To depth below centre of cutting $10\frac{50}{81}$, and consequently, the depth of said centre from the top, is $23 - 10\frac{50}{81} = 12\frac{31}{81}$.

Of the Form of Locks.

The most natural form of the lock is that which approaches, as nearly as possible, to the figure of the boats which are to use it. The width must be only a little more than that of the boat, and it must be the same throughout, as the boat has to pass along the whole lock; and the length may only exceed that of the boat by a space sufficient to admit of working the gates. A long rectangle is therefore the natural figure. It consumes the smallest quantity of water in passing the boat; is filled and emptied in the shortest time; and, on the whole, is constructed at less expense than any other form.

Palpable as this appears, however, it does not seem to have occurred to the early builders of locks.

Those of Fig. 1. and 7. Plate CCCCIX. from the Languedoc canal, are of an oval and circular form in the chamber. Those of the canal of Brussels, and various others in Holland, are of an octagonal shape, and sometimes calculated to admit several vessels at once. This system, however, is attended with great delay to the navigation, and it is surprising that, in some of the later canals, such as that from Louvain to Mechlin, (where the majority of the locks are conducted upon judicious principles,) there should have been a large basin lock introduced at its middle, which requires half an hour to fill or empty.

The great Sas or Lock at Slykens, near Ostend, which admits at one time eight vessels of 300 tons, is, in some respects, more justifiable; because, this being a tide-lock, permits several vessels to rendezvous there at a proper time of the tide, and therefore acts as an entrance basin for the canal above.

In the canal of Languedoc, the oval form of the chamber appears intended to oppose a greater resistance to the thrust of the earth when the canal is empty. It is certainly stronger than a straight wall of equal thickness would be. But it has been well shown, by Gauthy, that this advantage is in a great measure ideal; for, granting that the concave form may be well calculated to resist the thrust of the earth, yet it may possibly happen that the drying and settling of the earth may cause it to part from the masonry, in which case, if the wall be tight, the greatest pressure on the wall will be that of the water, when the lock is full, and this pressure, of course, acts in a more disadvantageous way. Besides the thickness which it is necessary to give even to the curved walls to secure them against filtration, by a partition of grout or cement work, would be sufficient to enable the straight wall to resist the thrust on either side.

But the true cause why these curved walls, and all enlarged forms of lock-chambers, should be rejected, is, the great loss of water and time which they produce, and which, in the canal of Languedoc, is as much as 5 to 3, the area of the oval lock being 338 square metres, while that of the rectangular lock for the same situation would only be 209, and also the additional expense of construction, which, in the floor, is also an excess of two fifths, and is considerable even in the side-walls.

Having thus determined the preference to be given to locks of a rectangular form, as in Plate CCCCIX, Fig. 9. from Perronet for the canal of Burgundy, and Plate CCCCX. Fig. 1. from the Caledonian canal, our next object is to consider their length and breadth. This must depend on the size of the vessels for which the locks are intended. When the vessels are to be navigated also on rivers or the sea, the breadth of the locks must be more considerable than where canal boats are intended to pass; for, in rivers, the shallow water, frequently met with, obliges us to give the vessel an excess of breadth, so that her draft may be diminished as much as possible; whereas, in canals, we are masters of the depth of water, and find it more economical to restrict the breadth as much as possible, as we thereby diminish the evaporation, the expense of cutting, and the purchase of property. Dr. Anderson, and other writers on the subject of small canals, have not attended sufficiently to this matter, when they recommend widening the surface only of small canals, in order to give a greater facility of trackage.

In our English canals, the usual size of boats supposed fit for the navigation of rivers and canals alternately, is one of fourteen feet beam. Where the canals are intended also to be used by coasters, greater widths are adopted. Thus the Forth and Clyde Canal admits vessels of 19 feet beam; and the Caledonian canal, which is a canal of transit for sea going ships, admits vessels of 39 feet wide; but, in the great majority of canal navigations in England, a much smaller width has been adopted. Seven feet beam has been the usual size in the central canals, and still narrower boats have been proposed; but they become liable to many inconveniences, and can only be employed in the transport of very heavy substances, such as ores or minerals.

The narrow boat has the advantage of being navigated with more ease, and of causing less expense in lock gates, bridges, &c.

Length and Breadth of Locks.

The length and breadth of lock chambers ought to be necessarily regulated by the form of the boats that are to pass upon the canals. It is common to make this kind of boats longer and narrower than those of rivers, which, on account of the small depth of water found in some places, are obliged to be made as flat as possible. In canals, on the contrary, we are able to give a considerable depth to the water, but we do not give them great breadth, so that there may be less evaporation, less earth to be removed, and less ground to be occupied.

There is commonly no more breadth given to canals than what is necessary for enabling two boats to navigate with ease beside each other, and even in the difficult parts, such as those which are cut in rock, there is often no more breadth given than what is necessary to pass a single boat, only some places are made wider, at which one boat may lay by, while another passes in an opposite direction. Besides, a principal object in making use of narrow boats on navigable canals, is to diminish the breadth of the lock-gates, which wear longer, and are more easily worked, than when they are broad. Narrow boats are also more easily drawn than those which are wider and shorter. But what ought principally to regulate the width and breadth of locks, are the dimensions of those in the canals already executed, and through which the boats of the new canal may have to pass.

Of the Profile of Lock Walls.

This is one of the most important cases of the general subject of retaining walls, and has attracted a good deal of attention from various writers. In general, it has been customary, especially among the French engineers, to adopt a profile similar to that used by Vauban, in the revetements or retaining walls of fortifications; and although the higher part of the walls used by that celebrated engineer to face his parapets of 18 feet thick had only a thickness of three feet, and stood well; yet, from some imagined necessity in the case of locks, this thickness at top was, by Belidor and others, considerably increased. One reason for this was probably the upright face of the lock-wall; for the profile of Vauban batters in front one-fifth of the height, and thereby increases the base, and consequently the stability of the wall; whereas the face of a quay or lock-wall was seldom made to batter more than one-twelfth, and frequently was made nearly perpendicular.

The backs of these walls were either made perpendicular to the top, or diminishing by steps, and, in some cases, assisted by wooden land ties. It was observed by one of our ablest engineers, the late Mr. Jessop, that this form caused the walls frequently to settle forward at the top, from the front of the foundation having comparatively a great weight upon it, and the back but little. To obviate this defect, he made the walls of equal thickness from the base upward, leaning them backward, so as by retiring the centre of gravity to enable the wall to resist better the lateral pressure.

The use of inverted arches for the bottom of the locks was not, he said, much known at that time; but, after their introduction, our engineers have adopted, especially on good foundations, a profile, which, commencing at the bottom with a considerable inclination or batter, rises gradually in a curved form, until at the summit the face be perpendicular to the horizon. This wall has, in some degree at least, in the lower part, the properties of an arch, and the joints and beds of the stones being carefully formed perpendicular to the face, each course is prevented from sliding on that below. The French, on the other hand, use horizontal beds even in the battering face of the walls, and are thereby deprived in a great degree of the advantages of the leaning wall. Though we cannot in this place be expected to enter much into the theory of retaining walls; yet we may observe, that, in general, by writers on this subject, the real principles of action have been much misunderstood, and false maxims of practice have been adopted even by experienced practitioners.

Though the problem has been treated of in a variety of different hypotheses, yet it is usually supposed that the earth, if unsupported by the wall, would tend to slide down the inclined plane, which is called its natural slope, and which may be greater or less according to the consistency of the earth or stuff to be supported.

The triangle of earth, therefore, between this inclined plane and the back of the upright retaining wall, may be looked upon as a sort of wedge, of which its own gravity is the acting power, and it is supported by the reaction of the inclined plane of earth and of the back of the wall, each of course acting perpendicularly to its plane.

If ABCD, Plate CCCCVIII. Fig. 11. be the section of the wall, and BCE of the moveable part of the earth supported thereby; then taking G the centre of gravity of the earth, and F that of the wall, and drawing the perpendiculars GH, GI, GK, and FL, GH represents the direction of the gravity of the earth, GI the direction of the support given by the firm inclined plane CE, and GK of the horizontal thrust against the wall ABCD. The back of the wall is supposed to be smooth, and of course only to be acted upon perpendicularly; and the wall itself to be a solid mass, which can only be turned over the front angle of its base or toe of the wall D. It resists this by its own weight, which of course may be supposed to be concentrated in the centre of gravity, and to act in the verticle line FLW. If W, therefore, represent the weight of the wall, and P the horizontal thrust of the earth, MD and DL will be the two arms of a lever, by which these forces are kept in equilibrio.

Now we know, that MD, or KC$=\frac{2}{3}$ BC; that the weight of earth is proportional to the area BCE, *i. e.* to $\frac{1}{2}$BC×BE; and that this weight in GH is to the thrust in GK as EB : BC. The thrust is therefore $=\frac{1}{2}BC^2$; and multiplying by its distance MD from the fulcrum D, that is by $\frac{2}{3}$BC, we have its oversetting force $=\frac{1}{3}BC^3$. Therefore the oversetting force of earth supported by walls of equal thickness is as the cube of the height.

Now for the counter resistance of the wall it is evident that its weight will be as the area ABCD, which, in a rectangular wall is BC×CD; and in that case also we will have the distance LD from the fulcrum $=\frac{1}{2}$DC, so that the resistance is $\frac{1}{2}BC\times CD^2$, making this force equal to the former, or $\frac{1}{2}BC^3$, we find $CD=BC\sqrt{\frac{2}{3}}=8165$ BC.

The breadth of an upright retaining wall must be therefore proportional to the height, and to be of equal specific gravity with the stuff, must be upwards of four-fifths the height. The specific gravity of stone and brick walls is indeed a little greater than that of the earth to be supported, and of course the above thickness may be somewhat diminished; but still it is so totally different from what is found sufficient in practice, that it might have suggested to the mathematician that there was some radical defect in his hypothesis.

Accordingly it has been endeavoured to amend this, by supposing the earth to act, not parallel to the horizon, but in lines parallel to the slope EC; so that the line of action from the centre of gravity of the earth meets the upright face of the wall at one half of the height of the said centre, and therefore the rivetting force is supposed to be diminished one half, on account of the shorter distance from the fulcrum, (Hutton's *Math.* ii. 196.) and in this way the thickness of an upright brick wall, to support earth, is calculated to be $\frac{4}{7}$ of the height, of a stone wall $\frac{21}{44}$, or above half the height.

Now this is still not only very different from practice, but is evidently erroneous in principle; for, in the first place, we cannot suppose a force to act against a plane, and be resisted thereby in any other way than perpendicular to it. And if we introduce the principle of friction to explain it, then it is evident that we ought not only to reduce the supposed pressure in the ratio of its obliquity to obtain the horizontal thrust, which is not done, but also that the part of the force which is thus resisted by friction becomes an addition to the weight and consequent stability of the wall. Nay further, if the line of action of the earth can be thus taken oblique to the surface of the plane of the earth, then, as there is no reason why it may not be supposed to proceed through the wall in the same direction, if on being produced it fall within the base, there will in fact be no resisting force, and the wall will stand and support the earth independent of its *own weight*, and may therefore be made of any open structure that will be firm; a proposition that is true in fact, and of great and well-known importance; for curved walls, and arches to resist earth, are of daily occurrence in civil engineering, though it is evidently not that which the investigation professes to inquire after, which was the thickness requisite for a wall to resist by its weight alone. The oblique action necessarily involves a corresponding modification of the back surface of the wall.

Several practical maxims may, however, be deduced from the foregoing mode of investigation. It is evident the wall cannot fall on the side next the earth, therefore, by making it lean backward, not only is the triangle of earth or acting power diminished, but also the wall itself, by having its centre of gravity removed further from the point of conversion at the toe, is the better enabled to resist the thrust. According as the wall is made to batter or lean backwards, therefore, its thickness may be diminished until it becomes a mere pavement over the natural slope of the earth; all that is necessary being to secure the foot of it from sinking or sliding forwards, and the beds from sliding on each other. But we must take care that the earth behind be well rammed or puddled as the work proceeds, to prevent any settlement from taking place in the masonry.

Nevertheless, builders have very slowly and unwillingly agreed to this form of wall, wishing the security of their work to depend on itself alone They readily agree to the batter in front, but dislike the leaning behind, and inclined beds of masonry. Such walls, therefore, have been usually built plumb or upright at the back, and with a slope or batter in front, of one-fifth or one-eighth of the height; and this is the form in which the thickness of walls has usually been calculated. The celebrated profile of Vauban, so much employed by military engineers, differing from this only in having at times an upright parapet wall at the top of five feet high and three feet thick, and there being square counter forts behind the main part of the wall.

Muller, among others, has given a variety of tables for the thickness of retaining walls. According to his principles, the general result of the simple profile above mentioned is, that with upright walls the thickness is .385 of the height, and with a batter of one-fifth, the average thickness is $\frac{3}{10}$ths of the height, or the thickness of the wall at top, and, exclusive of the battter, is $\frac{1}{5}$th of the height.

In calculating these tables, he has supposed the wall to be strengthened by counter forts behind of the same height as the wall, their length is $\frac{1}{4}$th of their height, and breadth $\frac{1}{4}$th of their distance from centre to centre. With this addition, the thickness of the wall at top becomes $\frac{1}{8}$th of the height when the batter is $\frac{1}{5}$th; and the avearge thickness of the whole is $\frac{1}{10}+\frac{1}{8}+\frac{1}{10}=\frac{3}{16}+\frac{1}{10}=\frac{23}{80}$, or between $\frac{1}{3}$d and $\frac{1}{4}$th of the height. And though this author supposes that the action or thrust of the earth is diminished one third by the resistance of motion along the inclined plane or natural slope of the bank, a supposition which, whether true or not, we do not think can be admitted in his view of the subject; yet this is the thickness of the wall which forms merely an equilibrium to the thrust, and consequently is the smallest possible.

Now nothing is more certain than that this thickness of wall very far exceeds what is ever found necessary in practice, and some important element must have been lost sight of in the calculation. A late writer thinks this may be corrected, by introducing the cohesion of the mortar and cement. But surely no practical builder would ever think of trusting to the cohesion of green walls. Besides, what cohesion is there at the foundation, which is supposed to be the place of fracture; and though we should admit that to be rock, and that the cohesion will increase in time, yet so does the thrust of the earth; for it is only after settling a little that its pressure becomes dangerous.

It is to the form or construction of the wall that the builder must look for the means of resisting this pressure at the least expense. As far as depends on the mass only the theory is true; but there are other means of adding to the resistance, which we now proceed briefly to consider.

In the first place it is evident, if any account is to be taken of the friction or resistance which the earth meets in tending to slide down the inclined plane, that the same reasoning may be applied to its friction on the back of the wall. Now this is a quantity which the architect can regulate at his pleasure; for, to make the back of the wall smooth as the mathemation supposes, although often done by the workmen, is absurd. Projecting stone set-offs, scorbels, &c. not only bind the wall much better to the earth behind, but have this much more important consequence, that a considerable portion of the weight of earth being supported by them, we derive from the very oversetting cause a supply of strength to the wall, and applied in the situation where it acts to the greatest advantage.

Nevertheless, the writers on the subject have hardly ever taken notice of this circumstance. The French have continued implicitly to follow the profile of Vauban for retaining walls, which has given their discussions, considering the little practical utility of them, an unnecessary degree of complication. For lock-walls, Belidor makes the thickness equal to the depth of water, without any sufficient reason, but to be secure, as he says, against all accidents; and he strengthens this still farther by counterforts; but this construction is only a useless waste of masonry.

Some practical engineers have treated this matter differently. Coehorn, in his fortification, has given a very ingenious construction for a retaining wall. His designs were intended for the soil of Holland, where stone is not to be found, and it behoved him to be as sparing of masonry as possible. His wall is only three feet thick, battering considerably in front, and leaning nearly as much behind, supported by long and thin counterforts, which are connected together by two rows of arches, one over the other; and also by two walls arched horizontally against the earth. The intervening spaces are filled with gravel and splinters, for the purposes of defence, which is also the reason of his counterforts being made so long, and connected by double walls. Coehorn does not give this as his own invention, though he describes it very carefully, but as having been adopted by him from some older German authors.

Gauthey, a civil engineer in the French service, who constructed the canal of Charolois, or of the Centre, about thirty years ago, has published a very sensible paper on the subject of walls, in the Memoirs of the Academy of Dijon. After criticising the theories of Couplet and others, given in the Transactions of the Academy of Paris, and the profiles of Belidor and Vauban, he proceeds to show, by experiments made with sand and shot against a smooth plane, that the pressure acts at the centre of gravity, or one-third of the height of the wall, and is the same, whatever be the slope; that in a plumb wall, if the weight of the wall be three times the acting power of the earth, and base $\frac{2}{9}$ths of the height, there is an equilibrium against oversetting. The acting power in practice is one-fourth of the weight of the triangle of the earth, with a slope of 45°, or one-half of the square of the wall.

He then shows, that retreats on the back of the wall may be made, so as to take off all acting power, and that a wall of 2 feet thick and 30 high, battering $\frac{1}{13}$, with counter forts of 3 by 4, and 18 asunder, joined by two arches of 2 feet thick, is abundantly strong. Such a wall he employed with success for one of the quays of the Saone; and it is evident, that the saving of masonry, compared with the common construction, is immense.

The writer of this article had occasion, a good many years ago, to turn his attention to this matter, and made various experiments on the subject; these led to, and confirmed, a very simple and general theorem for the resistance of walls, whether against earth, running sand, or water, but with which we shall not trouble the reader in this place. We shall only observe, with respect to the advantage of the friction on the back of the wall, that in one experiment, by the aid of properly managed corbels behind, a perpendicular wall of brick on bed was built 20 courses high against loose sand without derangement. The wall being only half brick thick, the corbels were made by laying one brick endways in the wall, so that half of it projected behind. It was also remarkable, that when, by heaping on more sand, or by ramming, the wall was pushed outward at the top, it continued steady, and did not fall until it overhung the base considerably more than its own thickness.

Lieut. Col. Pasley, of the Royal Engineers, has, with his usual talent and originality, investigated this subject in his instructions to sappers and miners. He minutely details a numerous set of experiments, which afforded results similar to what have been here described. From what has been already established, we are justified in recommending it to the practical engineer, to turn his attention to the advantages to be derived from constructing the back of retaining walls with a batter, and creating friction by projections and offsets.

But in the walls of locks, more must be attended to than the pressure of the earth alone. A film of water inserted between the back of the wall and the earth, will act hydrostatically against each of them, will counteract the aid which might be derived from friction, and if the lock be emptied in that state, may overset the wall inwards. But the hydrostatic pressure of the water within the lock can hardly do any harm, seeing the motion of the wall must be prevented by the resistance of the earth behind: hence the utility of counterforts behind the wall, is mainly that of cutting off the communication between one portion of such a film of water and another, so that the action being confined to a smaller space is the less dangerous, as the wall also derives a kind of abutment from the counterforts. The upper part of the lock wall, so far as the water rises and falls thereon, is (unless water be very abundant,) usually made perpendicular, its thickness, therefore, must be so calculated as to resist the pressure of water of equal depth, and taking the specific gravity of stone as $2\frac{1}{2}$ times that of water, this thickness will be the depth multiplied into 0.365, or a little more than $\frac{1}{3}$, and one half the depth will be sufficiently ample in any case.

The lower portion of the lock may be suited to the shape of the vessels which navigate through it, and therefore it will permit the wall to be made with a considerable batter, or slope, to the front, by which means the point of conversion being farther removed from the centre of gravity of the wall, the stability will be considerably increased without an increase of materials; but it must be observed, that the point of conversion itself must be sufficiently secured. To prevent sliding, it ought to be inserted someway into the ground of the foundation. If built upon a timber platform, it ought to be provided with an abutment; and if upon piles, they ought to be driven in the direction of the thrust, which will be nearly that of the face of the wall. Now, as the opposite wall of the lock requires the same precautions, and its action is directly in face of the other, by joining the bottom of the walls by an inverted arch, we not only destroy the horizontal thrust, but also extend the foundation, which, in the case of soft ground, becomes of great importance. The inverted arch has been much employed in this situation by our late British engineers. On the Continent, we believe, it is still the practice to rely on a platform of timber, or even a simple flat pavement, especially where the ground is firm. See the figures of the locks for the Canal of Burgundy. Plate CCCCIX. Fig. 9.

In the timber countries, as Russia, America, and even Holland, where stone is scarce, we have locks, of which not only the floor, but even the sides, are constructed of wood; as shown in Plate CCCCXI. Fig. 1, 2, 3, 4. In such cases the thrust of the opposite sides are sometimes made to balance each other by cross pieces over the lock, placed between the upright posts which support the planking of the sides. Instances of this may be seen on the River Lea.

But there is yet another principle by which the profile of the lock-wall must be regulated: The transpiration of the waters from the upper pond to the lower, beneath, or by the side of the lock, must be prevented. This is effected by rows of sheet, or plank piles carried across the site of the lock, and driven a considerable way under its foundation. Let us suppose the farthest downward of these rows to be water-tight, while the upper are not so, a film of water will introduce itself under the floor of the lock, and, being connected with the upper pond, will act upward against the floor with a pressure equivalent to the head of water, or difference of level between the waters above and within the lock. This will tend to float the lock upwards like a ship, and unless the weight of the side-walls be sufficient to counteract this, the bottom or floor will give way, or be blown up, as is the technical phrase. The floatation of a timber floor will aid this operation, while the weight of an inverted arch will, to a certain extent, resist it. This forms one of the greatest objections to timber locks, and in them it is perhaps advisable that the dams of sheet piles should not be brought below the upper gates;

but as all locks must at times be emptied for the purpose of repairs, &c. we have still the head of water of the lower pond, or ordinary depth of navigable water to be resisted. The floor, therefore, must be carried a considerable way into the land, and thereby loaded by the adjoining earth; or, if built within a river, it must be kept down with stones, &c. laid over the cross-beams, projecting on each side. See Fig. 1. Plate CCCCXI. which represents a lock on the Witigra. Or the floor and sides may be bolted to piles driven as firm as possible into the bottom, thereby as it were nailing the lock to the ground.

The floatation of the lock and weight of the side-walls will counterbalance each other, when the section of the masonry in the walls and bottom is two-thirds the area of the open space of the lock. Plate CCCCVIII. Fig. 12. For we may assume the specific gravity of the building as $2\frac{1}{2}$ times that of water; it will therefore compensate for an opening of $1\frac{1}{2}$ times its bulk, when the whole is immersed. The average thickness of the walls, therefore, where there is no invert, would require to be one-third of the width of the lock. Where there is an invert, the thickness will be much less, but may be readily found from the above. Brick walls would of course require a greater thickness than those of stone; and here we may perceive the importance of those means by which the weight of the adjacent earth is made to rest upon the back of the wall, for we thereby obtain an additional counterpoise against the floatation without expence. Puddling behind the walls is therefore resorted to with great propriety.

It is needless in this place to be more minute in the calculation for the thickness of the walls; the principle may be easily understood and applied when wanted. Besides, with respect to locks, it is rather an extreme case, as they are rarely exposed to greater differences of pressure than the ordinary rise of the navigation. For tide-locks and graving-docks, however, it is of high importance to guard against the hydrostatic pressure on the bottom: and serious accidents have taken place where it has not been sufficiently attended to.

We proceed, therefore, with the practical construction of the lock itself.

The site and dimensions of the lock being determined, the first object is the excavation of the lock-pit, or place for the foundation. In small canals, and navigations carried above the level of the neighbouring vallies, this is seldom attended with any difficulty, the excavation being, in most cases, level free for drainage; but in great locks connected with rivers, lakes, or the sea, it is often necessary to go to a considerable expense; and, in many cases, all the resources of hydraulic engineering are required to keep the excavation clear of water, or, when that is impracticable, to make a foundation independent of it.

The varieties of soil and situation render it impossible, in such a work as this, to give general rules for proceeding in all cases. We have already given some general principles under the article Bridge, and it will, we believe, be most useful for the young engineer to relate a few cases of noted difficulty and magnitude. Several good examples of that kind occurred in the construction of the Caledonian Canal.

Caledonian Canal.

Locks.—The Caledonian Canal is not only constructed on an unusually large scale, but, in consequence of various localities in the situation of its works, it affords much useful practical information to the civil engineer. Some of the most important instances are in regard to the sea-lock at each extremity of the navigation; also that which is placed at the upper or south-western end of Loch Ness at Fort Augustus.

With regard to the lock at the north-east extremity.—The shore of Loch Beauly, where the canal was to be connected with the tideway at Clachnacarry, near Inverness, being very flat, it was necessary to carry the canal, by artificial embankments, above 400 yards from high water mark into the sea, in order to obtain 20 feet of water upon, and without the lock sills, at high water of neap tides. But this shore, consisting of soft mud, into which an iron rod was easily pressed to the depth of 55 feet, it became doubtful whether a sufficiently substantial cofferdam could be constructed of timber, and also if any platform could be made equal to support the weight of masonry unavoidable in a lock of 180 feet in length, 40 feet in clear width, having 20 feet of water, besides a rise of 8 feet. Upon duly considering all the circumstances, a new mode occurred to the conductors of that work, and that was, by uniting the two earthen banks which were projected from the shore, at the place where the site of the lock was fixed, so as to form a solid mound over all the space which the lock would occupy; and this was done for the purpose of squeezing out the water, and consolidating the mud, by laying on a greater weight than the masonry of the lock: This was accordingly carried into effect. By the latter end of the year 1809, the mound was carried out to the necessary length, breadth, and height, and during its construction had sunk about 11 feet. A great quantity of stone was then laid upon the space the lock was to occupy, and levels taken to ascertain the precise height of the banks; in this state, matters were suffered to remain for about six months, until August 1810, when, having found that no farther sinking had taken place, the excavation for the lock-pit was commenced in the before mentioned artificial mound, a chain-pump, worked by six horses, kept the pit dry when sunk to 15 feet in depth. At that time a steam-engine, of nine-horse power, was erected, by which the water was commanded, and the excavation of the lock-pit was completed in June 1811. Before getting down, to about 30 feet below the level of high water ordinary springs, it was necessary to penetrate into the compressed mud about 8 feet, and the small portions of water which filtrated through the surrounding mounds of earth (in which puddle walls had been carried up,) was conducted in small gutters along the top of the compressed mud to the pump-well. As soon as the lock-pit had been excavated, rubble masonry, with lime mortar, was laid about two feet in thickness in the middle of the lock-chamber, and increasing to about 5 feet at each side; upon this the side-walls were founded, and brought up to the level of the top of the compressed mud, and then the inverted arch of squared masonry was put in, and the side-walls, counterforts, recesses, and wings, carried regularly up; the masonry of the bottom part was carried on by short lengths of about 6 yards at one time, in order to prevent the compressed mud again softening and being squeezed together in the open space. The above mentioned mud was found to be readily penetrated by piles, but when these were suffered to remain a few hours, no power could move them. The masonry of the lock was very successfully completed in August, 1812; the gates were afterwards put up, and the lock has been worked for several years. The whole is now in a very perfect state.

Corpach Lock.—The circumstances under which the lock at the south-western end of this navigation was constructed, differ greatly from what we have just described. It was found necessary to connect the canal with the tide-way in Lock Eil, at Corpach, on the north-west side of a rock, situated about 100 yards from high water; this rock was covered at three-fourths flood; and the lock was to be advanced so far into the sea, as to admit of the sill being laid upon the rock, where there should be 30 feet of water upon it at high water neap tides. For this purpose, water-tight mounds, faced with stone, were carried from the shore to beyond the extremity of the lock site. Between the extremity of these mounds, a wooden cofferdam was constructed. The clearing away the gravel, sand, and mud, the fixing the main piles firmly in the rock, and placing the wooden frames correctly in their proper places, were operations of considerable difficulty; but the success which attended a work of this magnitude and exposure, renders this mode deserving the attention of persons engaged in similar, or even inferior undertakings. As under the article Bridge foundations, we have minutely detailed every step of the process, it would be an unnecessary repetition to introduce the description here; we, therefore, presume it will be sufficiently satisfactory to refer to that article. Only, it may be further observed, that when the water had been excluded, and the rock excavated, no inverted arch was necessary.

Fort Augustus Lock.—The ground upon which the five connected locks at Fort Augustus were to be placed, consisting of coarse open gravel, and the lowermost of these requiring to be constructed so as to admit 20 feet of water upon the lower gate-sills at the lowest state of the water in Loch Ness; and the large river Oich, running upon the same sort of gravel, and close along the site of the lock, rendered it an arduous task to keep very large lock-pits clear of water; for the rise of these locks being only 8 feet, the foundations of the second and third locks were also considerably incommoded by water. This site for these locks, being by much the most eligible for the navigation, it was absolutely necessary to endeavour to surmount these natural obstacles. The first step was, in 1814, to turn the whole of the river Oich to the northernmost side of a small island, and occupy part of the south channel by the locks. A trial-pit was next to be sunk; and, by means of a small steam engine, of about six horse-power, it was carried to the depth of 18 feet; but here the water overpowered it. A pump-well was then begun, and an engine of 36 horse power, which had previously been provided, was erected. It commenced working in August, 1816, and the excavation of the lock-pit was carried on with all possible energy. It was continued as long as the flood-waters of the Oich would permit—was again commenced as soon as the state of the river would admit, in 1817, and during that summer and autumn the whole masonry of the lock, bottom, and wings, and the forebay, were got in; but, in order to command the water effectually, the engineer had, during that time, caused to be erected a third engine, of about nine horse power, which happened also to be in readiness; and when the excavation was upwards of 25 feet below the surface of Loch Ness, and the whole of the gravel still coarse and open, the power of all the three engines was required. These lock-pits being sunk directly into a mass of gravel, no cofferdam could be of any service. Under the inverted arch and side walls of the lock, chamber, &c. rubble masonry (as has been described in the Clachnacarry lock) was constructed; but it was here laid upon, and mixed with, abundance of moss, and this was done in order to prevent any sand from percolating. At the latter end of the working season of 1818, the whole masonry of the lowermost lock had been built, also the inverted arch, and 14 feet in height of the side walls of the second lock; and likewise the inverted arch, and six feet of the walls of the third lock; so that, except for the purpose of putting up the gates, there could be no farther occasion for employing the steam-engines at Fort Augustus, and every risk was at an end.

In these three locks there has, therefore, been afforded, cases of soft mud, hard rock, and very loose gravel, as foundations for very large locks. For their form and dimensions, see Plate CCCCX. Fig. 1.

The sheet piles, or plank piles heretofore alluded to, being of frequent use in hydraulic architecture, may be as well described in this place.

They are sawn out of a thickness proportional to the strain they are intended to bear. The points are (Plate CCCCVIII. Fig. 13.) sharpened so as to have a bevel or chamfer to one side only, so that in driving, each may be forced close against the preceding one; still farther to secure the seam or joint against the transpiration of water, it is not uncommon to groove the piles as in Fig. 14. on one edge, and make a ridge or feather on the other to fit such grooves, so that the piles are, in driving, preserved in the same plane. Lastly, to save timber, the pile is frequently grooved on each side, and a slip or feather, which may be of harder wood, driven in between, so as to enter both grooves. The plank piles are preserved in position, by being spiked to sills, or horizontal beams of timber, extending in the line of the proposed sheet plank piling, and fastened to stout upright piles of baulk, placed at certain distances in the same line, called guage piles.

In the construction of a lock, one of the earliest objects of attention is the platform on which the gates are to traverse. It is usually formed of timber. A stout floor of plank is spiked or tree-nailed down upon sills, or transverse beams, which are laid across the lock, and their extremities built into the walls. The scantling of the sills and plank are proportioned to the fatigue they have to undergo. In great locks, there are usually two rows of whole baulk in thickness, laid close together over the whole floor, carefully bedded in a mass of water-tight rubble masonry; and, when the foundation is doubtful, longitudinal ground sills are laid below, then resting, if need be, on piles drove to a proper depth. A row of grooved sheet piles is driven across the lock at the upper and lower end of this platform, and the floor is carefully caulked to prevent any transpiration of water.

On this platform the sill of the lower gates is placed, its construction is that of tie beam and two rafters, having the angle or curve of the lock-gates; and as it has the thrust of the water to withstand, care must be taken to give it sufficient abutment. The platform of the upper gates is constructed in all respects similar to the lower. The sheet piling at the lower side is unnecessary; but care must be taken that the breast-wall or step of the lock be made water-tight, and carefully puddled upon the upper side. To prevent also its receiving any derangement from the blows of boats, &c. it is necessary to lay a wooden curb along the coping of this breast-wall.

In Ireland timber has been sparingly used in the construction of locks; good stone and mortar are, in general, easily procured there. The platform for the gates is made of hewn stone. The sill is of hewn stone, set on edge, and usually two feet deep, supported on the lower side by a horizontal arch, which, at the upper gates, forms the coping of the breast of the lock; and, to resist blows from vessels, the key-stone of this arch is supported by two struts of horizontal flagging passing to the sides of the lock, or by a counter arch in the hewn pavement of the platform.

In constructing the side walls, a recess is made on each side, to permit the gates to fall back out of the way of vessels; and it is not uncommon to make those for the upper gates act as waste-weirs or overfalls, to discharge the superfluous water of the canal into the paddle holes. These paddle holes are conduits of stone or brick, usually of a circular form, and about 18 inches diameter, by which the water of the upper level is conveyed into the lock-chamber. From the lock it is usually conveyed into the lower level through sluices or paddles formed in the gates, below the level of the lower water; but, in the upper gates, this is seldom practicable, for the breast of the lock being commonly higher than the lower level, a cascade would thereby be formed in the lock, which would be troublesome or dangerous to the vessels.

The conduits or paddle holes from each side are sometimes united at the back of the breast-wall, and discharge themselves through that into the lock. At other times they enter the lock separately in each side. In either case, the low level is preserved back to the place of entry, and the water is then permitted to fall down on a flat surface in the conduit, so as to break its progressive force as much as possible. The paddle itself is usually a square of cross planked wood, sliding up and down in a rabbeted frame of timber, fixed in the stone mouth of the conduit or paddle hole. The lateral pressure of the water makes it adhere closely to the frame, so that it is necessary not only to make it run with the grain of the wood, but also to have a considerable power to move it. This is done by a crank and pinion, working into a toothed rack, which is fixed on a bar or handle, rising from the paddle up to the top of the bank or gate. Sometimes screws are used instead of rack and pinion, and various other ingenious contrivances have been proposed, so as to make the paddle turn on an axis, either in its own plane, or at right angles thereto, like scouring gates, &c. One of the simplest modes we have seen of getting rid of the hydrostatic pressure and friction was proposed by Mr. John Duncombe, viz. to make the entrance or mouth of the paddle hole a horizontal circular opening, and stop it by an open cylinder ground to fit it, and rising of the same diameter to the surface, where it could be lifted by a lever or other means, like the waste pipes employed in some cisterns. The waste water of the canal would of course escape over the upper lip of the cylinder, and pass along the paddle holes as usual. Such a cylinder may be made of wood or iron

The hollow quoins are upright circular grooves wrought in the side walls at the extremities of the sills; they serve as a hinge-place for the gate, the upright post of which that turns in them is named the heel of the gate; the opposite posts which abut against each other are called the head-posts. The heel-posts are retained in their places by a pivot or gudgeon at bottom, turning in a cup set in the stone, and sometimes the reverse, the cup being set in the heel-post. The upper part of the post is embraced by an iron strap or collar, which is carried back some way into the side-wall, and firmly secured. The hollow quoins are commonly cut out of large scantlings of stone, or brick is moulded for the purpose, and cast-iron has also been employed on the Caledonian canal. The exterior portion of the lock, above the upper and below the lower gates, are named the forebay and tailbay of the lock. The side-walls are then made to splay away outwards to the usual breadth of the canal, so as to facilitate the entrance of vessels, and still farther to guide them; there are not unfrequently fender-beams, supported on piles, continued to some distance above and below the lock, and running into the bank on either side.

Strapping-posts are also used to check the way of the boats in entering the lock; and, in the passage-boats on the canals in Ireland, a broad shield of iron is placed on each side of the stem, and dropped under the quarter when the boat approaches a lock. It is readily hauled up again when the boat gets under way. It is the invention of Mr. Sisson Darling, late secretary to the Grand canal.

Lock-gates are framed usually of timber, though iron is also used in some of the small canals in England, and has lately been introduced in framing the large gates for the Caledonian canal. The head and heel-posts are connected by cross-beams or rails turned therein; the upper and lower bars are firmly attached by straps and bolts, and the whole planked over, usually in an oblique direction, by way of giving an additional stay to the framing. The head-posts must be brought truly to the angle of abutment. If of iron, they have a ribband of timber bolted thereon, to soften the blows they receive. The heels must be wrought to a circular form to fit the hollow quoin, into which the pressure of the water will force them home. The upper bar of the gate in small canals, is usually continued a considerable way beyond the heel-post, and left as heavy as possible, or is loaded so as to form a counterpoise to the weight of the gate, and a lever for opening it. In great locks, capstans are employed to work chains, leading to the middle of the head-post on either side. Various other contrivances have been adopted for opening and shutting the gates of large locks. In Holland, a boom or spar is commonly attached to the head-post, and brought over a windlass on the lock-wall, a little above the gate; a rope is made fast to the end of the spar, and taking two or three turns on the windlass, the spar end is carried to the other end of the spar, which thus, by means of the windlass, is made either to open or shut the gate. At Antwerp, the French have employed a rack-bar of wrought iron nearly in the same way. These heavy gates have usually a roller or truck-wheel placed under the foot of the head-post, and running on a quadrantal railway of iron, to facilitate their motion. With the same view, also, attempts have been made to give floatation to heavy gates. In Sweden, some gates were made for the dock of Carlscrona, which were to sink into a deep recess, and rise when wanted by the admission of, and again pumping out of, a quantity of water, on the principle of the machine called the camel. At the dock of Monnikendam is the best, and we believe the oldest boat-gate we have seen. It has three parallel keels, which fit into grooves in the side-walls, and, by admitting water, and extracting it again, it is made to sit down in its place, or float up so as to be removed when necessary; but though such vessels are peculiarly useful as stop-gates, or for docks, they are not well adapted to a constant navigation, where they must be frequently and readily opened.

The best angle for the sally of double lock-gates, is a subject which has occupied a good deal of the attention of scientific engineers. Belidor has given a solution of this in a sort of popular way, which by no means leads to the true one; but an abstract of his mode of reasoning may not be misplaced here. He supposes, or takes for granted, that of all the positions which may be adopted, the most direct and effectual support is given by one door to the other, when they are at right angles, and of course there can be no use for employing an acute angle, as that will only increase the breadth and expence of the gate, while also the pressure thereon will be proportionably increased. 2*d*, As the sally diminishes, so does the breadth of each gate, and consequently the hydrostatical pressure thereon; and the minimum is when the gates come into the same line, in which case the one does not at all support the other. Between these two limits, therefore, where in the one case the angle at the base is 45°, and the other 0°, Belidor concludes, that the best is the arithmetical mean, or where the angle at the base is $22\frac{1}{2}°$; and, by a calculation, he shows this will be very nearly when the sally of the gates is one-fifth of the breadth of the lock. Though this solution appears with figures and calculations, it is evidently any thing but mathematical investigation; subsequent writers have entered, some more loosely, others more carefully, into this inquiry; and, in particular, we would recommend a short treatise by Mr. Brunnings of Leyden, published at Haerlem in 1797.

The more usual way of considering this matter is as follows: The pressure of the water on the gate BC is in proportion to its breadth BC, the strength of the gate is inversely as its breadth BC, the effect of the pressure is therefore as the square of BC. The supports afforded to the gate BC by the other gate CA, is as the perpendicular AE, on its direction from the fixed point A. The strength of the gate is therefore as AE directly and inversely as BC^2; but AE is the sine of ABC, the radius AB—BC is the secant of the same angle to half that radius BD. The strength of the gate is therefore as $\frac{AE}{BC^2} = \frac{2 \sin ABC}{\sec.^2 ABC}$, or since the cosine is the reciprocal of the secant, as $\sin. \overline{\times \cos.}|^2$ of ABC, the angle at the base. The maximum value of this expression is, when the tangent of $ABC = \sqrt{\frac{1}{2}}$, or $= 0.7071$, or when the angle at the base is 35° 16″ nearly, and the sally of the gate is $\frac{7}{20}$, or somewhat more than one third of the breadth of the lock.

This is the same determination as that for the best position of rafters in a roof, &c. but it still takes but a very confined view of the subject. The pressure on the hollow quoins at AB is unnoticed; in general, these are so steady, that the abutments of the gates may be considered as immoveable. The strength of timber pressed in the direction of its length, is so much greater than against a cross-strain, that it cannot be valued in the same way. Much more reliance may therefore be placed on the support given by the opposite gate, especially when we consider the support given by the still, and a much more obtuse angle may be, and commonly is, given in practice to the lock-gates than the above, or even the arithmetical mean between 35° 16″ and 0°, which Brunnings has proposed, after the example of Belidor.

Silberschlag and Perronet recommend the sally to be one-sixth of the width as the common custom. In Holland, considerable variety however in this particular is to be found in that country. The celebrated sea-lock of Muyden has from one-sixth to one-seventh, the angle being 145°; and the ancient lock of Sparendam has in the sea-doors a sally of about one-sixteenth. It was built in 1568, and has stood many storms without injury. In this country it has been common of late to give a camber or arched form to great lock-gates, by which their strength is undoubtedly considerably increased.

In regard to the materials used in constructing lock-gates: before the Caledonian canal, they have been made of timber: but here, on account of the difficulty of procuring timber of suitable dimensions and quality, it was found necessary to have recourse to cast-iron; which, having answered the purpose, an example on so large a scale has led to the adoption of this material in many other instances, as in the New Graving Dock at Dundee, &c. &c.

The importance of this subject has led us to enter pretty fully into description and discussion respecting canal looks, but the necessary limits of this article prevent us from proceeding in the same manner with respect to the numerous substitutes for common lockage, which have, chiefly with the view of economizing water, been proposed and attempted in England; that is, to say, by means of solid plungers in parallel chambers, raising and depressing boats in caissons, or frames, by chains passing over large wheels, and by means of working air-vessels.

These have severally been projected and experimented upon by Dr. Anderson, James Fussel, Robert Weldon, James Woodhouse, Sir William Congreve, and others.

There is in each of these schemes much ingenuity, and we believe that each of them was successfully worked in model; a separate treatise would be usefully appropriated to their merits; but as none of them have hitherto been found to answer in general practice, they are inadmissible in a work, where there is scarcely sufficient room for an account of the modes usually practised in this busy country.

Inclined planes, connecting different canal levels, which have long been usefully employed in this country, have a just claim to attention; but as they in truth are a portion of railways, which will be treated separately, we must refer the reader to that head.

Reservoirs.

The mode of supplying a canal plentifully with water being essential to its prosperity, it generally employs the attention of the engineer, previous to determining the most advisable line. When it is necessary to establish a navigable communication between separate valleys or basins of country, and where a double lockage is unavoidable, the summit which divides them is generally too high to permit a regular supply of water being drawn directly from the streams on either side; or these streams are not unfrequently appropriated to the service of mills and manufactories, as in the cases of the Languedoc canal in France, the Grand Junction and many others in England, and the Forth and Clyde canal in Scotland. Under these circumstances, it becomes necessary to collect the flood-waters of the adjacent higher grounds into proper reservoirs, to be drawn off as occasion may require.

The choosing a proper situation for a great reservoir, requires all the skill of the engineer. Much must always depend upon local circumstances, but some of the principal objects to be had in view, are, 1st, That the reservoir should be sufficiently low to collect the flood-waters from an ample surface of country. 2d, It should be so high as to enable all the water it contains to be drawn into the summit of the canal. 3d, It is desirable that the basin to be laid under water, should contract towards its lower extremity, so as to require a comparatively short embankment or head; and this head should be placed upon a substantial foundation. 4th, It is very important that the bottom and sides of the reservoir should be naturally impervious to water, otherwise much trouble and expence will be required to render them so, by artificial means. 5th, The dimensions of the embankment will be regulated by its height, and the nature of the materials with which it is to be constructed. It is, however, usual to assume the height of the top bank to be from three to four yards above top water when the reservoir is full; the breadth of the top to be five yards; the outside to slope at the rate of three horizontal to one perpendicular, and the inside slope at the rate of two horizontal for one perpendicular. But both dimensions and form have been subject to very considerable variations; for instance, at St. Ferriol, upon the Languedoc canal in France, (Plate CCCCXII.) the embankment, or, as there denominated, *Digue de Barrage*, consists chiefly of masonry, of which there is about 57,500 cubic yards. There is one main wall, about 110 feet in height, and for 37 feet it is about 37 feet in thickness, above that it is about 17 feet, and near the top is about five or six feet. At the distance of about 200 feet from the great wall, in the outer side, there is another wall upwards of 60 feet in height from the bottom of the brook channel at that place; the space between these walls is filled with earth, and faced with clay. At an equal distance from the middle walls, on the inner side, there is also a low wall, at the extremity of the arched masonry vault, for drawing off the water, named *Voute d'enfer*. The construction of this vault, and its access, are complicated and expensive. The pipes and cocks for drawing off the water, are fixed in the great wall, about 10 feet above the *Voute de Vidange*, or vault by which the waters are conveyed from the locks to the channel of the brook Laudot below the reservoir. The access to the locks is by a separate arched passage upon a higher level, and the descent is by steps. Over the interior entrance of the voute D'enfer, which is, of course, about 200 feet within the reservoir, there is a pyramid of masonry which indicates the level at which the water stands. Besides these bottom vaults, or arched passages, there are two others at different heights, by which the upper portions of the water are drawn off. The length of this reservoir is about one mile, and its breadth near the embankment about half a mile. Along one side of the reservoir, there is an artificial channel by which the waters of the brook Laudot, and also those of other rivulets can be conveyed past the reservoir. The supplies of water are, as has already been described, derived from the Black Mountain, collected and conducted by feeders 38½ miles in length. The works of this great reservoir were commenced in November 1667.

In another large reservoir for the Languedoc Canal, (that of Lampy,) the Digue de Barrage, consists of only one immense masonry wall, which is about 40 feet in thickness at the foundation, and, exclusive of strong buttresses, 33 feet at the surface of the ground, and 18 at the top, which is 54 feet above the surface of the ground, comprising, in all, about 17,000 cubic yards of masonry. The water is here also taken off at three different heights.

In these reservoirs, it will be seen, that, as in the case of locks, the chief dependence is placed upon masonry walls; but they are admitted as being imperfect in regard to retaining water, and that they are in frequent need of repairs. Further experience has therefore led to the employment of much simpler, and, at the same time, much more effectual means; accordingly, in this country, puddle-walls, constructed in the middle of the embankment, or head, are only employed; and similar means prove also sufficient to secure the bottom and sides, even when the substratum is gravel, sand, or rock, intersected by open fissures.

As a specimen of British reservoirs, we have selected that now constructing about seven miles west of Edinburgh, upon Glencorse Burn, in a gorge upon the eastern side of the Pentland Hills. This, although not for a navigable canal, has been planned upon the model of the most approved canal reservoirs, by that intelligent engineer James Jardine, who also plans and conducts all the operations of the extensive water-works of this city, and who has, very kindly, furnished the drawing of his great reservoir for this work.

By inspecsing Plate CCCCXIII. it will be seen that the shape of the valley is so favourable, that with the very short embankment, or head, of 130 yards, a surface (when full) of 40 English acres, and 60 feet of depth at the deepest part, will be obtained. The foundations of the embankment, and tunnels for drawing off the water, are upon rock; and there is every prospect of the bottom and sides of the reservoir being also on rock impervious to water.

The dimensions of all the principal parts being marked on the Plate, it is unnecessary to enumerate them here. It will be seen, that, instead of enormously thick walls, there is here one made of puddle, about 15 feet thick at the foundation, and 9 at the top; and instead of a horizontal gallery, as at St. Ferriol, there is a circular vertical staircase, 8 feet diameter, down to the apparatus for drawing off the water. At the upper end of the reservoir there is to be a waste weir to enable (when found necessary) the stream of Glencorse Burn to be carried in an artificial channel along the northern side of the reservoir to the reservoir waste, which last is to be placed at the northern extremity of the embankment, and where the united waters of this waste and the Burn will be carried to a considerable distance from the embankment, and discharged over a rocky bank into the Burn channel.

The water will be drawn from this great reservoir at two different levels, viz. one at the bottom and the other at the middle of the height.

Of Waste Weirs.

The wiers connected with canals are of two sorts. 1. Those constructed across rivers to force the water from them into the conducting feeders, or immediately into the canal itself; and 2. Waste weirs, to permit the surplus water to pass off the canal.

The first being equally applicable to other purposes, such as mills, &c. the description of them belongs to another subject.

The second sort, or waste weirs, are varied in their form and materials according to circumstances; their site is chosen as nearly as practicable to the place where there is a great influx of flood water, in order that it may be discharged before there is too great an accumulation, or becomes injurious to the canal banks; it is also necessary to have wastes adjacent to locks, to convey water from upper to lower levels, without passing through the locks. The place of discharge should, when practicable, be where the ground has a gentle descent from top water of the canal, and where the surplus water may fall into a natural channel on the lower side of the canal. It is desirable that the bed of the waste weir should be upon rock or firm clay; if on clay, the simplest mode is to drive a row of plank piles in the canal banks along the inner side of a wooden sill, whose top should be level with the top water of the canal, and from that sill to form a paved channel for the water to flow down; sometimes, instead of driving piles, a wall is built in the canal bank, and coped with squared freestone laid in water lime mortar, and the coping stones secured by cast-iron dowels; it is necessary to secure the sides of the sloping channel by walls; and the lower extremities must vary according to circumstances, as must the discharging channel. If the waste is on the towing-path side, the water must pass under small arches or flat covered drains.

Of Aqueducts.

When the course of a canal crosses that of a river, it becomes necessary to build a bridge, and upon it, in place of a common road, to construct a channel and towing-path for a canal; the heights of the aqueduct is regulated by the relative levels of the river and canal, and its breadth by that of the canal. Until of late years, it was usual to make the aqueduct of such a breadth as to admit the canal channel, and its towing path, to be constructed either wholly of masonry, as in the case of some of the French aqueducts, or partly of masonry and partly of puddle, as in those built on the English canals; both these modes are exhibited in Plate CCCCXIV. where Fig. 1. and 2. represent the aqueduct de Cesse upon the Languedoc canal, designed by Vauban; Fig. 3. and 4. the Kelvin aqueduct upon the Forth and Clyde Canal, designed by R. Whitworth; and Fig. 5. the aqueduct over the river Lune upon the Lancaster Canal, designed by J. Rennie, all works of great merit, on a large scale, and having considerable variety of construction. In these aqueducts, excepting what relates to making a water-tight basin for the canal, there is little different from a road-bridge of similar dimensions; it is therefore only necessary to refer to the article Bridge for instructions respecting them.

But about the year 1795, Thomas Telford having been entrusted with the management of the Shrewsbury and Ellesmere Canals, had his attention drawn to the construction of some large aqueducts, and having observed, in several instances, the masonry of aqueducts where puddle was employed, to be cracked, and very subject to leakage, and some parts not unfrequently obliged to be taken down and rebuilt, or tied across by strong iron bars; these circumstances led him to consider of introducing cast-iron work. This he did, in the first instance, upon the Ellesmere Canal at Chirk, where the aqueduct was 600 feet long, and 65 feet high above the river; here he rejected puddle, built the spandrels over the arches with longitudinal walls only; across these walls cast-iron flaunched plates were laid, as a bottom to the canal, and also on purpose to bind the walls horizontally; these were well jointed, screwed, and caulked; the sides of the water channel were built with stone facings, and brick hearting laid in water lime mortar. By this mode the quantity of masonry was much reduced, yet the whole remains water-tight and substantial, after being worked 20 years. (See Plate CCCCXV. Fig. 1. and 8.)

About the same time, and on the same canal, it was found necessary to cross the River Dee, at the bottom of the celebrated valley of Llangollen, at Pontcysylte, at the height of 126 feet 8 inches above the surface of the river, and for 1000 feet in length, it was cheaper to aqueduct than embank. Here Mr. Telford introduced a still more decided deviation from the usual form, by building upright piers only, and, instead of masonry arches, putting cast-iron ribs between them, constructing the canal part by cast-iron flaunched plates for the sides as well as the bottom, and in order to preserve as much as possible of water-way, projecting the towing path over the water in the canal. The canal part is 12 feet in width, which admits boats of 7 feet beam, and a towing-path; by referring to Plate CCCCXV. Fig. 2, 3, 4, 5, 6, 7, the general form and particular mode of construction will be seen. This aqueduct has now been worked about 15 years, and has answered the purpose for which it was designed; where the embankment commences the height is 75 feet, but gravelly material being very convenient, rendered embanking cheaper than carrying the masonry and iron-works any farther.

In the three magnificent aqueducts recently constructed upon the Edinburgh and Glasgow Union Canal, the modes of the two last mentioned aqueducts are combined, that is to say, the masonry of the arches and spandrels are preserved, as in Chirk, and cast-iron plates for the bottom and sides, as in Pontcysylte, are introduced within the masonry; how far it was judicious to incur the expense of providing two modes of security in the same structure appears rather questionable. In Pontcysylte the upper parts of the piers only are hollow, with one cross wall in each; in the Union Canal, the piers are brought up hollow with cross-walls from the foundation; this mode, with an equal quantity of masonry, embraces a greater extent of base, and having more external and internal surface, ensures better materials and workmanship.

In some cases, where the level of the river and canal are nearly equal, the river water is made to descend on the upper side of an aqueduct, and after passing under it, to rise again on the lower side. In this case, it is evident that there is a risk of the aqueduct being lifted up by the river water during floods, more especially if the water happens to be taken out of the canal at the same time; a case by no means uncommon. It is necessary to provide against this risk, by laying a platform under the masonry of the aqueduct, bringing strong iron bars up through the piers and abutments, and connecting them with ribs, and some sort of covering over the arches and spandrils, so as to unite the whole mass together.

Of Bridges.

It is evident, that over canals bridges must be constructed for the accommodation of public and private roads, and for occupying fields intersected by the canal. Where the canal is navigated by sea vessels with standing masts, the bridges are moveable; where the vessels are without masts, the bridges are fixed.

Of moveable bridges there are various sorts. The earliest were lifted vertically like fortification drawbridges, which have no doubt been their model. Of late years, they have more usually been made to turn horizontally. Formerly they were constructed chiefly of timber, and are, we believe, so still in foreign countries; but in Britain they are now frequently made of cast iron. We have given a drawing of each in Plate CCCCXVI.

Of fixed bridges some are made of wood, and others of stone or brick, and some with stone or brick abutments, and timber or iron framing, roadway, and railing. There is little connected with these last mentioned fixed bridges, but what is common to some of those which are fully described under the article Bridge. We shall, therefore, here confine ourselves to giving the outlines of their general form with the towing or hauling path.

Besides bridges for the before mentioned purposes, there are places where it is necessary to change the hauling path from one side of the canal to the other. Here horse bridges only are frequently constructed, and which are of course made narrower and of more steep access than those which are intended for carriages.

On Skewed Bridges.

It often happens in situations where bridges are proposed to be built, that the course of the river, and the direction of the road over the bridge, cross each other at very oblique angles. This proves particularly often the case on canals, or inland navigations; to remedy which, it has been the custom, until of late years, and is so still in many instances, to direct the course of the river, or line of the road, and sometimes both of them, so as to make them cross each other at right angles, or nearly so, by which means the abutments of the bridge are made to stand square opposite to one another. But, to accomplish this, it is in many instances attended with a very great expense and labour, and in some cases is found impracticable; hence some desirable situations have been abandoned for others less convenient in other respects.

William Chapman, engineer, in an article on *Oblique arches*, (Rees' *Cyclopædia*.) states that he never heard of any alteration in the construction of the *arch* of the skewed bridge prior to the year 1787. At that "time he had the direction of the county of Kildare canal, a branch from the Grand Canal of Ireland to the town of Naas."

"In the course of conducting the work, several of the directors of that canal were anxious to have the line of the roads unvaried; therefore our author was led to consider whether the usual imperfect method could not be set aside, by the substitution of one on sound principles; and it then occurred that its leading feature must be, that the joints of the voussoirs, whether of brick or stone, should be rectangular with the face of the oblique arch, in place of parallel with its abutment; and consequently Mr. Chapman made the bridges over the county of Kildare canal to suit the line of the road, although the obliquity of one of them was carried to an extent beyond what he deemed eligible in practice, as will appear from the observations made on Finlay bridge near the town of Naas, which deviated 51° from a rectangle with the canal, and consequently formed the acute angle of 39° with its abutments. Its span in that oblique direction is 25 feet, and its pitch 5 feet 6 inches, or nearly $\frac{2}{9}$ths of its span. Mr. Chapman likewise introduced his improved method of constructing the *arch* of skewed bridges over large drains in the East Riding of Yorkshire.

Within these few years, in some situations similar to the above, a certain description of bridges very different from the common form, particularly in the arches, have been introduced, and found to answer the purpose extremely well, by which means neither the direction of the road, nor the course of the river or canal is altered. They have been built chiefly on inland navigations; and some of the more recently executed canals in England, offer several specimens both in brick and stone; as well as the Glasgow, Paisley, and Ardrossan Canal in Scotland. The difference between these (which we shall call for the sake of distinction, Skewed Bridges) and the common sort, consists chiefly in the construction of the arch, and particularly the top part of it. In common bridges, the courses of the arch lie all level between the two ends, and are parallel to the faces of the abutments; but, in the skewed bridge, the greater part of them run oblique to the abutments, and deviate from the level between the two ends, in proportion to the obliquity of the angle formed by the outsides of the bridge and face of the abutments, which angle in common bridges is a right one.

Since the face of the abutments stands at an oblique angle to the sides of the bridge, it is necessary that all the courses of the arch, except a few at the springing, stand nearly square with the outsides of the bridge, and consequently oblique to the abutments, in order that the two sides of the arch may have their pressures directly against each other, which is the essential property of the skewed bridge, and which makes it so much superior in strength to the common one: Because, if the courses of the arch run parallel to the abutments, when they stand oblique to the sides of the bridge, it is evident that the pressures of the two sides of the arch will not be opposite, but one side will press in a direction past the other; and if the obliquity be great, and the bridge narrow, it must of course fall, because in that case the pressures would miss each other altogether. This will appear still more clearly from the drawings.

Plate CCCCXVIII. Fig. 1. is the elevation of a skewed bridge which is built on the Glasgow, Paisley, and Ardrossan Canal, at Black Hall, near Paisley, where the abutments stand no less than 24 feet 6 inches off the square, on no more than 16 feet span of an arch, as appears from the plan and superstructure. In Fig. 2, AA represents the water in the canal, or the direction of the abutments; BB the road over the bridge; CC and DD, the parapets of the bridge; and EE, a tangent to the side of the bridge over the centre of the arch; *a b*, and *c d*, are two parallel lines in the direction of the courses of the arch stones, diverging from the line *b c*, which is perpendicular to the tangent EE, so as to be one foot asunder at ten feet distance from the point *b*; that is, the courses of the arch are brought within one foot in ten of the right angle, which makes the arch stronger at the acute angles of the abutments, than if they were brought quite to a right angle to the tangent. The faint lines in Fig. 1, drawn in the opening of the arch in a slanting direction, represent the oblique courses of the arch, which are all in that direction, except the first or springing course, which is horizontal, and corresponds with the courses of the abutment. A is a cross section of the water in the canal at the ends of the wing walls, F and F; and B is a section of the side wall of the bridge, shewing the curved batter. Every thing else on this plate is obvious fram inspection.

It will be proper to observe here, that what follows applies more particularly to arches built of lighter stones, there being no other materials which require such particular preparation, previous to their being set in their places; what we have hitherto said will apply to arched bridges in general, of whatever materials. But as the preparing of the stones, for an arch of this sort, has always been considered by the practical builder as a considerable difficulty, the following directions are offered for his assistance, which we hope will be found useful and acceptable to him.

The principal requisites, besides what are in common use amongst masons, are, first, a narrow-ended rule, Fig. 5. for giving a proper twist to the bed of the stones; second, a template* for working the soffit crossways, Fig. 4.; and, thirdly, a circular rule for working the soffit lengthways of the stone, Fig. 6. These will prepare all the stones except quoin-heads, which we shall speak of afterwards.

Fig. 3. *Construction.*—Draw the indefinite right lines AB and CD, parallel to each other, and the same distance asunder as the width between the abutments at the springing of the arch; and at right angles to them, draw the line BC, through its middle point at G, draw the indefinite right line FGE, parallel to AB; from G to F set off the height of the arch in the centre, and draw the semiellipse BFC, which is the true figure of the arch on the square, or at right angles to the abutments, H and I being its two foci, and K the centre for drawing the top part LFM; draw the lines KH and KI, and produce them to L and M, which points show what part of the arch is to be drawn from the centre K, and what from the centre H and I, namely, BL and CM; draw the line LM, which is the height to which the level courses in the present case rise, all above this being built on the skew principle.

Near to H or I, on the sides towards B or C, draw the ordinate or line *b b* parallel to the centre line EF, which produce indefinitely to *c*, as also the lines LN and MO. From any convenient point in CD, according to the size of your paper, as at P, draw the line P*q* parallel to BC, and from *q* to A set off the quantity that the bridge is off the square, namely, twenty-four feet six inches in the present case, and draw the line AP, which represents a tangent to the sides of the bridge over thec entre of the arch; or, if the side of the bridge was straight, it would be represented by the line AP. With a radius of ten feet from N, as a centre, describe the small arc *a a*, which make equal to one foot, and draw N *a*, which produce to O and D, so shall N *a* OD be a line at right angles to the courses of the arch, being one foot off the square in ten. From *d*, E, and *c*, draw the indefinite right lines *d d*, ER, and *c c* perpendicular to NO, observing that N *d* is equal to *c* O; make *d d*, and *c c*, each equal to *b b*, and ER equal to FX; through N *d* R *c* O trace the curve by means of the centre S, which will represent the figure of the skewed part of the arch; at right angles to the courses, produce ER to S, and to *v*, and from E to T in the lines ES, set off any convenient length from two to four feet, according to the length of the stones. Suppose in the present case two feet, draw T *e*, and *e c*, parallel to E *c*, and ET, so shall ET *c e* represent part of the course of the arch; from T draw T *i*, parallel to EF, and from *i*, draw *i m*, parallel to ER, draw the right line *m* R; and on its middle point the ordinate *r s*, draw also the line *m* S, and with a radius of four feet, or some such length at pleasure from *s*, as a centre, describe the small arc *n o*, and the figure is constructed.

Fig. 4. *Construction.*—Draw the indefinite right line A *c*, and from A as a centre, with the radius SR or S *c*, Fig. 3. describe the arc *a b*, so shall the angle *b a c*, equal *v* R *s*, Fig. 3. make *a b* of any convenient length, say fourteen inches, and *a c* eighteen or twenty inches, draw *c d*, and *c n*, parallel to *a c* and *a b*, at about two inches and a half asunder, which completes the template for working the soffit of the stones; the leg *a c* being applied on the bed, and the leg *ab* across the soffit.

Fig. 5. *Construction.*—Make it in all respects similar and equal to S *o n*, Fig. 3, and it will be a rule, which, being applied on the beds, at two feet distance, or that of ET, Fig. 3, from a straight rule of equal breadth at both ends, both being square across, and parallel fo each other, and made out of winding with the upper edges, will give the beds of the stones their proper twist when worked between with a straight rule.

Fig. 6. *Construction.*—Draw the right line *a a*, equal to ET, Fig. 3, or two feet long; on its middle point at *r*, set off the ordinate *r s*, making it equal to *r s* in Fig. 3. trace the curve through *a s a*, and produce it to a convenient length; at a proper breadth, say three inches from *s*, draw the other side of the rule, which may be straight, and it is finished. The curved side of which, being applied lengthways on the stone, will form the soffit thereof.

We have now proceeded so far as to enable the builder to form all the stones except the outer faces, or quoin-heads of the arch, which, in the present case, where the side-walls of the bridge are curved, both horizontally and vertically, is the most difficult part to accomplish; but in order thereto, proceed as follows:

Fig. 7. *Construction.*—Draw AB, AP, and BQ, which must correspond with NV, and part of NL and VM, Fig. 3. respectively; bisect AB in C, and draw CD perpendicular, producing it both ways from C; make CI equal to the height of the arch in the centre, that is equal to FX or ER, Fig. 3. Draw the curve AIB, so as to be a true representation of the skewed part of the arch on a tangent to the side of the bridge, over the centre of the arch which ACB represents; the method to

do which, is the same as was used for drawing the curve N *d* R *c* O, Fig. 3. Perpendicular to AB, set off H *o*, equal to two feet, or some such length at pleasure, so as to touch the line AP in *o*; do the same with L *d*, making it equal to four feet, or any other convenient length; from H and L, describe the curves HEK and LMN, each equal and similar to the curve AIB; from I to D, set off the height of your quoin-heads, and draw the curve FDG, so as to represent the top of them; with the radius of ten feet, and centre D, describe the small arc 3 *q*, equal to one foot, and draw D 3; parallel to which from *o*, draw *o b*, which is the direction for the courses of the arch; make A *m* equal A *b*, and draw *m* H, which is the direction of the courses on the soffit of the arch; mark off on AIB the courses of the arch, which may be either equal or unequal, through which, in a direction to the centre of the curve, draw the lines *m* T, VU, &c. as in the figure, to represent the joints of the courses round the arch; mark also off the courses on HEK, and LMN, exactly the same as on AIB, and through the corresponding marks draw the slanting lines W,W,W, &c. as in the figure, which will show the joints of the courses on the soffit, observing that they all meet the base line ACB, at the same angle, namely that of AH*m*; draw the curved lines RCS, to represent the front of the wall, or side of the bridge, as also D 7 *v z* to represent the curve and batter vertically, and the figure is constructed.

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* Template, a term much used amongst mechanics, and signifying a mould or pattern.

Now, to make templates for any of the quoin-heads, suppose that of *u w*. From *t*, *u*, and *w*, draw *t* 8, *u*, 9, and *w p*, parallel to DC, and *t* 6, *u* 7, and *w* 5, parallel to AB; draw also from 5 the dotted line to —, at 6, and from 6 the black line to —, at 7, both parallel to DC, and 8 *x*, parallel to AB; also from *s*, where the joint cuts the curve HEK, draw *r s*, perpendicular to *w t* produced.

Fig. 8. *Construction.* Draw *m n*, and make it equal to H *o*, Fig. 7. equal to two feet; at right angles thereto draw *m o*, and make it equal the height of the quoin-head *t w;* draw *n r* parallel to *m o*, and *o c* parallel to *m n*, set *s t*, Fig. 7. downwards from *n* to *r*, and draw *m r*, so should *r m o*, be the template of the side, if the bridge was straight and plumb. Set also —, at 6. Fig. 7. inward from *o* to *c*, and draw *m c*, then would *r m c* be the template of the side, if the bridge was straight lengthways, and had the same curved batter vertically, but as the bridge is also curved on the side lengthways, set 4 *p*, Fig. 1. back again from *c* to *s*, and draw *m s*, so shall *r m s* be the true template, and is to be applied at *s t w*, Fig. 7.

Fig. 9. *Construction.* Draw the lines *m n*, and *m o*, at right angles as formerly, making always the line *m n*, equal to H *o*, Fig. 7. and *m o* equal to *t w*, the thickness of the course; from *w* to *r*, set off at right angles downward, the short line *r s*, Fig. 7. and draw *m r*, which, with *m o*, would form a template if the side of the bridge was straight lengthways and plumb; from *o*, set off outward to *c*, the small space —, between the short black line and curve at 7. Fig. 7. and draw *m c*, which with *m r*, would be the template suited to the curved batter; but, to make one to answer the curve lengthways also, from *c*, still outward to *s*, set off *x* 9, Fig. 7. and draw *ms*, so shall *r m s* be a proper template in the present case, and is to be applied at *s t w*, Fig. 7.

Fig. 10. and 11. are templates to be applied at Y Fig. 7. but as letters of reference cannot be inserted without confusing the figure; and as the lines are drawn from which they are formed, it is hoped they will be understood, after Fig. 12. and 13. have been described, as the methods to be used, are much the same in all of them.

To make templates for the quoin *c n*. From *a*, *c*, *n*, and *b*, Fig. 7. as formerly, draw the right lines *a y*, *c z*, *n v*, and *h l k*, parallel to AB, and *a l*, *n g*, *c h*, *z* 2, and *v* 1, all parallel to CD; the centre lines also from *f*, where the joint cuts the curve HEK, draw as above, *f e*, perpendicular to *a n* produced.

Fig. 12. *Construction.*—Draw *m n*, and *m o*, at right angles to each other, making *m n*, as formerly, equal to H *o*, Fig. 7. and *m o* equal *a n*, the height of the quoin-head, draw *m r*, and *s c*, parallel to *m o* and *m n*, set *a f*, Fig. 7. upward from *n* to *r*, and draw *m r*, which, with *m o*, is a proper template, providing the side of the bridge was straight and plumb; but for the sake of the batter, set 1 *y*, Fig. 7. inward from *o* to *c*, and draw *m c*, also on account of the curve lengthways. Set *k g*, Fig. 7. outward again from *c* to *s*, and draw *m s*, so shall *r m s* form a proper template to be applied at *f a n*, Fig. 7.

Fig. 13. *Construction.* Draw *m n* and *m o* at right angles as before, making *m n* equal to H *o*, and *m o* to *a c*, Fig. 7. to which draw *o s* and *n r*, parallel respectively; set *f c*, Fig. 7, upward from *n* to *r*, and draw *m r*, which, with *m o*, would form a template suited to the case of the bridge, being straight lengthways, and plumb on the sides: but, to make one agree with the batter, set 2 *y*, Fig. 7. inward from *o* to *c*, and draw *m c*. Again, to adopt it also to the curve lengthways, set *h i*, Fig. 1. still farther in from *c* to *s;* draw *m s*, and *r m s* is a proper template to be applied at *f a c*, Fig. 7.

As above directed, proceed to find templates or moulds to every joint, and across every quoin-head, observing that one template will suit both quoins up the sides of the same joint.

It must also be observed, that the legs of the template will not be quite straight, the leg *m r*, in all of them, must have the same curve as the rule, Fig. 6. and in the whole length of the leg *m s*, Fig. 6. the curve will be equal to both the curves between *v* and *y*, and between *b* and *g*, Fig. 7.; that is, if the curve between *v* and *y* was half an inch from a straight line, and between *l* and *g* a quarter of an inch, then would the curvature in the whole length of *m s* be three quarters of an inch, and so of others.

The first quoin stone at A, as well as at the other three angles, must be formed quite different to the other quoins, their soffit must be of a triangular form, of any convenient size, but exactly similar to A *o* ⊙, Fig. 7.; because upon this depends the proper pitch, or direction of the courses; the angle at *o* will be at the outside of the bridge on the acute, and the side A ⊙ on the obtuse corners, A *o* being the laying bed. They are constructed thus: From *m* draw *m* ‡, perp. to AB, and from ‡ draw ‡ △, perp. to A *o*, produce *o b*, to cut △ ‡, produced at ⊙, and draw A ⊙; so shall A *o* ⊙ be similar to the soffit when the side of the bridge is straight lengthways, and also plumb. But, to give the outer heads the proper curves and batter, they must be worked to templates made as for the other quoins, which will shift the point ⊙ considerably nearer to *b*, in the present case; but the angle at *o* must not be altered. The top bed must be worked to the template, Fig. 4. and the bottom one to the template made to fit the arch at L or M, Fig. 3. It should be observed, that all drawings made for obtaining the actual dimensions of rules, moulds, or templates, should be drawn to the real size of the part, upon a large floor or platform; or, if no such place can be found large enough, the drawing may be made to half, or even quarter of the full size, that is to a scale of three inches to a foot, but never to a less, if any degree of accuracy is required.

The above directions being well understood and digested, will not only enable the builder to construct any arch on the skew principle with ease and accuracy, but may also be of great use to him in forming the quoin-heads of other sorts of arches, which has been considered difficult, such as common arches on a circular plan, with either a plumb or battering front, or upon a straight plan and battering front, as well as several other varieties, which are all comprehended in the above, and their requisites found nearly in the same manner, enough with much less difficulty; as they are more simple of themselves, it is easy to perceive that by bringing the courses of the arch nearly square with the sides of the bridge, the span of the arch is increased, in the proportion of the line BC to NO, Fig. 3.; and the height continuing the same, the arch in effect becomes much flatter, and consequently the horizontal pressure on the abutments must be greater. But as the pressure comes on the abutments in a direction that increases the thickness of them in the same proportion, the strength of the bridge is not affected thereby: Hence the same thickness of abutments as would be necessary for a square bridge, will be sufficient for one of the skewed sort.

This part of the article which relates to skewed bridges, is more valuable, from having been furnished by Mr. Henry, who constructed several with perfect success on the Glasgow, Paisley, and Ardrossan Canal, he being the resident engineer for that undertaking.

Stop-Gates and Let-Offs.

In order to limit the injury arising from accidental breaches in canal banks, occasional gates are constructed upon the canal, which, when shut, serve to interrupt the course of the water. They are usually placed at each end of an embankment or aqueduct, or where there is an opportunity of drawing off the water, and discharging it into a natural course or channel, in order to empty, repair, or cleanse the canal.

Of stop-gates there are various sorts. 1. Those which are placed in the canal bottom, lying partially afloat, so that any motion in the canal water shall make them rise and shut against the vertical frames in the masonry of the abutments on each side. These, in theory, are perfect, because they require no personal attendance; but in practice they are either so easily moved by the boat's motion, as to expose them to be struck, and rendered useless, or they are so heavy, as not to be moved by the motion of the water, and are besides very liable to be covered with mud or other matters in the canal bottom. On these accounts they are now seldom constructed. 2. Some stop-gates are made to be drawn across the canal from a recess on one side. They run or slide upon a sill in the bottom, and shut into a shallow vertical groove in the opposite abutment. They are drawn across by a chain or pole with a hook, which works in a ring or staple fixed upon the moveable gate, being thus drawn across the canal current to operate as a double stop-gate. In a narrow canal they answer very well, but when the canal is broad the current acts too powerfully upon them while shutting. 3. The simplest, and perhaps the safest stop-gate, is the common lock upper-gate. As these are usually only opened in one direction, they are called single stop-gates; and two pair are required to enable different currents to be obstructed, and to constitute a double stop-gate. But, 4. By contriving a moveable post for the head to shut agains , one gate is made to open either way, and so act as a double stop-gate. In Plate CCCCXIX. specimens of each of these gates will be seen, and their construction and mode of working will be evident on inspection. In the district of canal between stop-gates, there must be an opportunity for drawing off the water. This is done by means of sluices upon openings in the canal sides or bottom, connected with drains or aqueducts, where the water can be conveniently discharged into a natural channel. These are denominated let-offs.

Conclusion.

To this article, the subject of which has of late years become of so much importance in this country, it will be evident we have allotted an extent rather disproportioned to a work of this nature, and yet have been obliged to pass over many matters more briefly than could have been wished, and even omit others entirely; but we trust that the most essential points have been satisfactorily discussed, and a considerable portion of original matter introduced. For instance, what regards Egypt, Holland, and the Low Countries, Sweden, America, Ireland, and Scotland, must be admitted as entirely original; also much that regards many of the most important navigations in England, the Fen drainage, and also much that relates to foreign countries. The scientific discussions and practical illustrations are chiefly original, and we only regret that our limits do not allow of more ample details; but these can only be expected in a separate work, for which this country would afford abundance of materials. But, in publications of this sort, we are so far behind our neighbours on the Continent, that the Archduke John of Austria, when in England, expressed astonishment that nothing had been published respecting the aqueduct of Pontcysylte, (which he had been to see,) and said that in France it would have produced three folio volumes.

We must acknowledge much neglect in omitting to register the operations of difficult works, so that successful efforts, or even pernicious failures, might prove useful to others. But, on the other hand, in this country, from these circumstances, there are few merely book-learned engineers, who, without practical experience or skill, and with very superficial knowledge, abound in troublesome self-sufficiency, and are fertile in useless projects. In a busy country, the numerous great works prove a great practical academy; and as the general principles of science are abundantly discussed in other publications, the natural ardour of British workmen for attaining excellence, and the competition of their masters in the general market have, without the aid of particular publications, risen to a degree of perfection which excites the admiration of our learned neighbours.

In this country we find that the most valuable inventions and improvements originate not from the depths of science, but from ingenious practical skill, engrafted upon a few general principles, and proceeding from observation and experiments. It has therefore been our object not so much to perplex with elaborate diffuse discussion, as to touch upon the most generally useful points and render these plain to the workman, to give him a general view of the progress of his art in different countries, rouse his attention as to its importance, show him specimens of different works, and stimulate his desire to imitate and excel them.

NAVAL ARCHITECTURE, See SHIP-BUILDING.

NAVIGATORS' ISLANDS is the name given by Bougainville to a cluster of 10 islands in the South Pacific Ocean, in consequence of the inhabitants performing all their journeys in canoes, and never walking from one village to another. They are situated between 169° and 172½° of west longitude, and to the south of latitude 13° 25′ S. These islands, which appear to be volcanic, form a fine archipelago, and possess considerable interest on account of their arts, their productions, and their population. The villages are very agreeably situated on the sides of brooks descending from the mountains, and their huts, which are very elegant, are built under fruit trees. Pigs, dogs, fowls, birds, and fish abound; and the islands are covered with cocoa, goyava, and banana trees. The sugar-cane grows spontaneously on the banks of the rivers. The inhabitants, who are very numerous, are tall and well-formed. They manufacture cloth composed of real thread, obtained from some filamentous plants, and also mats of paper stuffs. See La Perouse's *Voyage*, vol. ii. p. 191.

NAXIA, or NAXOS, the *Strongyle* of the ancients, is an island of European Turkey, and forming the largest of those called the Cyclades, in the Grecian archipelago. This island is covered with high mountains, whose base is schistose or granitic. White marble, and a hard calcareous stone, are superincumbent on the schistus. In the highest of these mountains, called *Dia*, or *Zia*, is a grotto of beautiful white marble, which is regarded as a sacred spot. In the east part of the island there is a mine of emery. The hills and eminences are covered with myrtles, arbutuses, lentisks, hypericums, savories, thorny brooms, leguminous shrubs, and the rock rose which yields the labdanum; oleanders, agnus castuses, and plane-trees abound on the banks of the rivulets.

The productions of the island are wheat, barley, kidney beans, garden beans, and other legumes for home consumption; oranges, lemons, bergamot citrons, peaches, apricots, pomegranates, pines, plums, almonds, walnuts, and figs, are abundant. Cheese is exported to Constantinople, Smyrna, and Salonica, to the amount of 9000 francs annually; cotton, silk, and flax, are cultivated to a small extent. Oil is made to the extent of 35,000 francs annually. The island contains sheep and goats, small-sized oxen for husbandry, and mules and asses for draught.

Naxia, the capital of the island, is beautifully situated on an eminence by the sea side, on the west coast of the island. The walls, with which the Venetian princes defended it, have to a considerable degree escaped the ravages of the Turks. The Latins, who were once masters of the country, are all lodged within their enclosure, and the Greeks occupy the new town, which stretches to the east of the castle. "The old town," says Oliver, "stretched to the north, towards the fountain which bears the name of Ariadne. There are still below the castle some remains of a subterranean aqueduct, which probably conveyed to the city the water of a copious spring which is seen four or five miles to the east, and which at present waters a part of the plains of Naxia." The fountain of Ariadne is only a simple rill of water, and but for its classical associations, would not attract the notice of the traveller. Bacchus had a temple at Naxos, the gate and foundations of which are still visible on a small rocky island near Ariadne's fountain. A bridge, built on a chain of rocks, is said to have united this island to the large one, and to have supported an aqueduct for bringing water to the priests who inhabited the enclosure of the temple.

In lately excavating some foundations, a statue of a woman of a fine form was discovered; and to the north of the island, near the quarry where the block had been obtained, was found an unfinished colossal statue of Apollo. The population of the town is nearly 2000; that of the island is about 10,000, 8000 being scattered up and down in 41 villages. The annual taxes, which the island pays for the land, the koratch, and the customs, is about 1670*l.* The catholic inhabitants, who are constantly diminishing, amount only to about 600, and are established in the town. They have an archbishop, a co-adjutor, six canons, a rector, and several curates. The Greeks are rapidly increasing, and their clergy are less numerous, but more rich than those of the catholics.

From the peculiar situation and advantages of the island of Naxia, M. Sonnini proposed to the French government to make it the seat of a particular commerce, which he wished to see established in the islands of the Levant. Ships of burden may anchor in summer under shelter of a rock off the harbour. East longitude 25° 26′, and north latitude 37° 7′. See Tournefort's *Voyage au Levant*, vol. i. Olivier's *Voyage dans l'Empire Othoman*, tom. i. p. 307—318; Sonnini's *Travels in Greece and Turkey*, chap. xxxv. p. 456, 462.

NEAGH LOUGH, See IRELAND.

NEALING, See ANNEALING.

NEBULÆ, See ASTRONOMY.

NECKER, JACQUES BARON DE, a distinguished financier and statesman, was born at Geneva, in the year 1732. His father, Charles Frederic, was professor of civil law there, and became known to his contemporaries as the author of some treatises relating to jurisprudence. Intending to bring up his son for the mercantile life, he gave him a suitable education, which was hardly completed, when the situation of clerk in a banking house at Paris having offered itself, Jacques was sent away to occupy it, at the age of fifteen. The allurements of a capital could not divert the young man from steadily discharging his humble duties, and sedulously consecrating all his unoccupied time to increase his general knowledge, and remedy the defects of his scanty education. Thellusson, his master, had observed this regular conduct; but it did not strike him that, under an exterior somewhat shy and repulsive, Necker concealed any talents beyond the ordinary, though valuable qualities of punctuality and discretion. An accident first revealed the existence of higher powers, and laid the foundation of Necker's future greatness. It happened, one day, that the head clerk, who had to transact some important business at the Exchequer, was prevented from attending to it at the appointed hour, and the business, in consequence, devolved upon Necker; who, guiding himself by the aspect of the case, managed the affair in a way contrary to his master's directions, but so as to secure for him a profit of 500,000 livres, beyond what could have been acquired otherwise. This occurrence naturally attracted notice; and being followed on the part of Necker by the same prudent carefulness which had marked his previous conduct, it introduced him to the confidence, to the chief employment, and, finally, to the partnership, of his principal.

Necker was now on the high road to wealth. Thellusson having died shortly after, he established a bank of his own, in which a brother, and some other merchants, had shares: he speculated with the East India Company, with the English funds; was cautious, enterprising, successful; and in the course of fifteen years had amassed a princely fortune. But the possession of a capital beyond that of the most opulent house in France (it amounted to six millions of livres), could not render the career he was prosecuting so successfully, and the kind of distinction which he might acquire from it, interesting enough to engage all his ardour, and limit all his views. He aspired to reputation of a more exalted species; and his previous acquisitions in literature and science enabled him to take an honourable mode of obtaining it. Political economy, begun under the auspices of Colbert, systematized and new-modelled by Dr. Quesnay, expounded by Turgot and a multitude of inferior men, was at that time eagerly studied in France; and Necker's profession co-operated with the bent of his genius to inspire him with a taste for the fashionable subject. He had examined it maturely, not without dissenting in many essential points from the sect then prevalent, and since named *Economists;* and in 1769, when the propriety of the East India Company's monopoly was keenly disputed, he published a book on the question, wherein he endeavoured to defend that establishment against the objections of Lacratelle and Morellet. It is a strong proof of the author's ingenuity, that his work was popular, though it maintained so unpopular a side of the argument, and respected among men of letters, though it went counter to the fundamental principle of Dr. Quesnay's system, which they almost universally patronised. The *éloge* of Colbert (read at the *Academie Francaise* in 1773), and a tract on the Corn Trade which followed it, tended greatly to establish Necker's reputation as a political economist: and the consideration resulting from his immense fortune, together with the esteem he enjoyed in the literary world, paved the way for his advancement to a station in the government, where such talents might be immediately applied to practice, and were now, more than ever, imperiously called for.

It has been said that Necker did not entirely rest his claims to office on the strength of public opinion which backed him, but employed the intervention of the Marquis de Pezay, by means of whom he maintained a concealed correspondence with the young king, and transmitted him memorials, insisting on the resources of the state, and painting, in bright colours, the immense improvement which might result from properly using them. Prompted by those glowing representations, or impelled by the national voice, Louis at last consented to admit Necker into his finance department. It was at first attempted to make the new Comptroller-general divide his powers and his duties with the old; but eight months of experiment showed clearly enough that the two could not act in concert; and Taboreau being dismissed, Necker obtained the sole management of his post, on the 10th July, 1777. His conduct in it gave general satisfaction. He retrenched and borrowed; and by many judicious arrangements materially bettered the condition of the treasury. The middle ranks, who felt the practical benefit of this procedure, approved his character, and extolled the disinterestedness (which his enemies called the ostentation) of serving without a salary. Excepting Turgot, whom his doctrines on the corn trade had alienated, the literary class regarded him with favour, and exulted at the triumph of liberal opinions in this first instance, since the edict of Nantes was repealed, of a Protestant being advanced to any important situation in the government. With the court party he was less successful; his measures thwarted their prejudices and their interests: but the rectitude and calmness of his demeanour, and the powerful support he received from without, were sufficient to impress them with respect, and to frustrate their cabals.

Necker was now in the place he desired: his administration of it was applauded; and the five subsequent years, though always full of toil, and seldom free from anxiety, were perhaps among the happiest of his life. He was fortunate in the possession of an amiable and highly-gifted wife,* whose attentive management relieved him from domestic cares, while her affection and accomplishments made his home at all times a scene of comfort and peace. He was employed in labouring for the welfare of a great nation. Buffon, Marmontel, Thomas, and all the most celebrated men of the age, embellished his leisure; and he might flatter himself as being the architect of his own fortune, and think, with more than usual plausibility, that his own powers and his own merit had earned him all this exaltation.

So splendid a condition was not, however, destined to be permanent. Necker, it is true, continued to enjoy the unabated, or even increasing confidence of the public; the *Compte Rendu* (1781,) in which he developed his plans of finance, was circulated to an unparallelled extent; and among the 200 000 copies of it that were sold, few were perused with other feelings than approbation. But his enemies at court were still active. The expedients he recommended for alleviating the national burdens, or allaying the popular discontent, were viewed with suspicion and repugnance; and a claim which he put forward, soon after the publication of his *Compte Rendu*, to a right of being received into the Council, and which he supported with more spirit than prudence, was eagerly seized on; and being dextrously improved, it led to discussions which forced him to give up his appointment. He resigned on the 28th of May, and withdrew to Copet, a chateau which he had purchased lately on the banks of the lake of Geneva.

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* This lady is in some sort connected with the literary history of England. She was the Susanne Curchod, the object of Gibbon's early passion, the rise as well as the "decline and fall" of which is told with so much stateliness in his autobiographical fragment. Her father, M. de Naas, a Protestant clergyman of the Pays de Vaud, had improved her promising faculties by every species of culture. She was intimately versed in literature, ancient and modern, and united a keen relish and a great capacity for such pursuits, with all the grace and softness which adorn the female character. M. de Naas died prematurely, and left his family in straitened circumstances; which induced Susanne and her mother to settle in Geneva, and undertake the establishment and superintendance of a boarding school. Necker found her in this capacity, and had the sense to appreciate her worth: a Madame de Verminoux, having a son to instruct in Latin, took the young lady with her to Paris for that purpose; the acquaintance begun at Geneva, was here renewed, and in due time ripened into marriage. Among the refined and intelligent circles of Paris, Madame Necker maintained her early distinction. At one time conversing with philosophers, at another watching over the necessities of the poor, she was eminent throughout all her life for the extent and force of her intellectual powers, no less than for the ardour and benevolence of her heart. To Gibbon, notwithstanding his highly *prudent* desertion of her, and the wide difference in their religious opinions, she displayed not the slightest resentment; but treated him always as a brother, and often corresponded with him in the kindest and frankest manner. She wrote several works of considerable repute, which will be enumerated afterwards.

It was natural to feel keenly the immense change in his circumstances; and to a mind so active and aspiring, particularly when it had already drunk so deeply of the sweets of power, this change must have been more than usually galling. But Necker had not abandoned the hope of resuming his station; and the warm reception bestowed on his treatise *De l'Administration des Finances*, published during his retirement, was well calculated to strengthen such anticipations. Courtiers might stigmatize him as a demagogue, whom his position in society rendered a natural enemy of the privileged orders, and whose ideas of a representative government, like that of England, were fraught with danger; but the ineptness and prodigality of Calonne, his successor; the increasing agitation of the kingdom; the increasing embarassments of the ministry, all pointed to a thorough alteration of system, and to Necker as the man for effecting it. Animated by those prospects, he returned to Paris in 1787; and as Calonne had accused him, before the Notables (then assembled to provide against the growing dangers,) of malversation in his office, and unfairness in his accounts, Necker instantly prepared a memorial to rebut this charge, of which it was easy to demonstrate the falsehood. He submitted his defence to the king, but refused, at his request, to suppress it; and was in consequence ordered to retire to St. Ouen, a country seat many miles distant from the capital. This banishment, however, was not of long continuance. Calonne's dismissal, which the publication in question contributed to hasten, and Bienne's appointment to succeed him, were found inadequate to the emergency; the financial difficulties, the popular discontent, went on increasing; and Necker was recalled, in the month of August, 1788.

Such a reinstatement might well be gratifying to his vanity; but the task he had to perform was appaling. On one hand were a dilapidated treasury, and a ruinous, though insufficient taxation: on the other was an impoverished and tumultuous people, from whose scanty resources he behoved to make good this defficiency, while he felt that in their favour consisted his only security against the intrigues of a court which viewed himself and his principles at once with fear and aversion. His first step, after devising means to relieve the pressing scarcity of corn, was to insist on the removal of Maurepas, the prime minister; and having now the chief direction of affairs in his own hand, he urged the King to fulfil his former promise of assembling the States General,—as the only means of calming the popular ferment, and effectually remedying the grievances of the nation. The States General were convoked accordingly; they met on the 5th of May, 1789; but their meeting produced none of the anticipated effects. To Necker, far from realizing his favourite project of a limited monarchy, it afforded nothing but a series of disappointments and vexations,—placing him in a situation where it was impossible to reconcile the wishes of his master (or his master's advisers) with the wishes of the people, and thus forcing him to vacillate between co-operation and resistance with regard to both. In his dread of the *noblesse* he had settled, that the deputies of the *tiers état* should be equal in number to the two remaining orders united; an arrangement which soon brought about the junction of all into one National Assembly, where the democratic influence decidedly prevailed: and the plan of a constitution, by which he still hoped to quiet the rising demands of that party, was so altered and curtailed by the King, that Necker refused to be present when it was read. Vehement contentions ensued, in which the voice of moderation could no more be heard; violent, yet feeble efforts on the part of Government, but served to irritate the deputies; and as Necker refused, notwithstanding their intemperance, to concur in the attempt to overawe them by a military force, and was besides regarded as a lukewarm friend, if not a concealed enemy to the royal interest, he received a secret order, on the afternoon of the 11th July, 1789, to leave Versailles privately within twenty-four hours. He complied without hesitation, and instantly set out for Brussels. But his departure produced a result very different from the proposed one. Coupled with the gradual approach of a great army to Paris and Versailles, it inspired the populace with vague terrors, and enabled designing men to exasperate them into frenzy. On the memorable 14th of July, the mob rose and levelled the Bastile to the ground, massacred every obnoxious person, and delivered themselves up to all manner of excesses. To appease them, Louis was glad to despatch a courier in pursuit of Necker, requesting his immediate return. He returned accordingly; and his journey from Basle, where the messenger found him, to the capital, resembled a long triumphal procession.

It was a proud thing for Necker to be received at the gates of Paris by the acclamations of assembled thousands; to have his bust paraded through the streets; and his house emblazoned by the inscription, *Au Ministre adoré*; but this brilliancy was not more lasting than the proverbially unstable nature of popular applause might have led him to expect. With the most earnest desire to act uprightly and honourably, he soon found it impossible to unite an attention to the real interests of the state with the favour of an excited and ignorant mob,—perpetually misled by wicked agitators,—yet drunk with its new-found power, and indulging the most chimerical expectations from the actual posture of affairs. Necker's mature judgment rendered him hostile to the extravagant and precipitate innovations which were sanctioned by the Assembly, and tumultuously hailed by the populace, who now overruled and intimidated all parties. With equal ingenuity, keener ardour, and superior eloquence, Mirabeau confronted him like his evil genius; and, being totally without scruple in the employment of any expedient, honest or the contrary, was but too successful in overturning all reasonable proposals, and conducting the people to that state of anarchy, out of which his own ambition was to be gratified and his own exertions rewarded. When, to meet the immediate necessities of Government, Necker submitted the project of a loan, and offered to contribute a large sum from his private fortune towards it, Mirabeau insidiously seconded this measure, and made it a handle for the production of various accounts, before a select committee,—who, being at once devoted to his views, and ignorant of finance, brought out a report equally injurious and irritating to Necker, and thereby completely overset his declining popularity. His previous declaration in favour of the royal *veto*, though strictly conformable to those opinions which he had formed, and often expressed long before, had prepared the misguided people for listening to any accusation against him; and his opposition to the destruction of the noblesse, attributed to anxiety for his own acquired baronship, exasperated this distrust into open detestation. He was branded as an aristocrat; his personal safety was endangered; and he felt that it had now become high time to retire. Leaving his share of the loan, (above 80,000*l.* sterling,) together with a large portion of his property behind him, he accordingly quitted Paris, and returned to Switzerland, travelling by the same road, on which, a few months before, his presence had excited such enthusiastic bursts of joy. The feeling was again as enthusiastic, but its character was altered. Necker secured himself with difficulty from the execrations of those who had so lately blessed him. At Arvis-sur-Aube, he was arested in his journey, and a decree of the National Assembly became necessary for allowing him to proceed. At Vesoul, notwithstanding of this, his carriage was stopped anew: a short time ago, they had unyoked this same carriage, and drawn it in triumph through their streets; they now loaded with curses the object of their former idolatry, and threatened, or even attempted, to murder his attendants.

Arrived at Copet, far from the turmoils, the hazard, and the splendour of his late situation, Necker had leisure to reflect on the great scenes he had witnessed or shared in, to view the obscurity into which he was fallen, and to collect the scattered elements which yet remained to him of happiness or contentment. It is rare that a degraded minister enjoys much peace of mind, or can extract pleasure from those sources on which human life must generally depend for its comforts. Whoever has participated largely in the spirit-stirring strife of power, who has struggled with its difficulties, and triumphed in subduing them, will find a void in his heart when such excitements are withdrawn, a languor and disquietude, which objects less vast and imposing are altogether incompetent to remove. In Necker's political history, every thing was grand and surprising; the game he had played was deep as well as fluctuating; and when he lost it, his feelings did not belie the common maxim. "I could have wished," says Gibbon, after a visit at Copet about this period, "to have exhibited him as a warning to any aspiring youth possessed with the demon of Ambition. With all the means of private happiness in his power, he is the most miserable of human beings; the past, the present, and the future, are equally odious to him. When I suggested some domestic amusements, he answered with a deep tone of despair, 'In the state in which I am, I can feel nothing but the blast that has overthrown me.'"

Time, however, which extends its quiet influence to every sensation of sorrow or of joy, did not fail to mitigate this despondency. Necker, indeed, still felt that he was banished from the country where his highest hopes had been centred; but the esteem of impartial men over all Europe, the secret approval of conscience, were not denied him: three-fourths of his fortune might be engulphed in the confusions of France; but enough still remained for the gratification of his charitable dispositions, and the support of his family in dignity and independence. By degrees his ambition directed itself to the more peaceful arena of literature and political philosophy, he composed various treatises in support of the doctrines formerly professed by him, and the line of conduct by which he had endeavoured to put them in effect. Among his enemies, too, as faction succeeded faction, the misrepresentations which had tarnished his name, began to clear away; the French government, which had at first proscribed him as an emigrant, erased this mark of reprobation, and charged their army, when it entered Switzerland, to treat him with every kind of respect. His pursuits were soothing, and shared by those whom he loved; and though his domestic comfort was rudely assailed by the death of Madame Necker in 1794, there still remained an illustrious daughter, who viewed him with a reverence and affection truly filial, and whose brilliant powers it was a delightful task to unfold. His care, in this particular, was amply recompensed: Madame de Staël, even before her father's death, had gained a literary reputation above that of any female in Europe; and the writings which subsequently marked her splendid, though too short career, will preserve her name to a distant posterity. Her own affectionate and impassioned character, her lonely situation, the unwearied and condescending kindness of her father, made it a pleasure and a duty for Madame de Staël to watch over his declining age with the tenderest solicitude. She seldom quitted him, and had reluctantly obeyed his injunction to recreate and instruct herself by a visit to Germany, when Necker was seized with his last illness. He died, in her absence, on the 9th of April, 1804.

With a fate common to all who have lived in times of political agitation, and thus blended the memory of their actions with that of events, which give force and expression to every fierce quality of human nature, Necker has been painted in the brightest and the blackest of colours, as the varying prejudices of historians have chanced to sway them. By one party he is reproached as the author of the French Revolution, and charged with all its horrors; by another he is eulogized as the virtuous and enlightened statesman, by whose guidance, too little appreciated and lost in factious clamour at the time, all the advantages of a reform might have been secured without any of its evils. His character, we may safely assert, has been greatly exaggerated in both cases. The French revolution might be accelerated or retarded, it could not be prevented or produced, by any such circumstance as the conduct of Necker. And if his measures gave form and occasion to the troubles which followed; who can *yet* say under what different management the issue would have been milder or more salutary? By the candid of foreign nations, Necker is now considered as a minister possessed of talents entitling him to an elevated place among politicians, and of integrity deserving perhaps to set him at their head. His talents, doubtless, were exercised, where their exercise was too powerless to be of any benefit: but the high moral rectitude of his deportment, preceded, followed, surrounded, as it is, by perfidy, and cruelty, and baseness, forms a bright spot, on which the mind gladly reposes amid the general gloom.

It was unfortunate for Necker, but the natural consequence of his situation, that his political views, being formed in the closet, had too much of a speculative cast, too little fulness of detail, for comprehending all the multifarious elements which influenced the result, when tried in practice. He had visited England, and admired our constitution; but he knew only its outlines, and applied them too hastily to France, where so much was at variance with their application. In another point of view, it was also unfortunate that his ambition was at once so high, and so urgent for immediate gratification. Yet it ought to be remembered, that if this love of popularity, too undistinguishing and too eager for perpetual nourishment, betrayed a want of the firmness essential to a great man, it had a close kindred with many of the qualities which constitute an amiable one. It appeared in the shape of vanity at times, but of vanity nearly allied to those benevolent affections which rendered Necker's conduct no less simple and exemplary on the theatre of politics, than it was endearing in his domestic circle. In the latter respect, whatever may be the thought of the former, few indeed can lay claim to an equal tribute of praise. By his family he was viewed with a sentiment approaching to idolatry, and his daughter never consoled herself for his loss.

As an author, Necker displays much irregular force of imagination, united with considerable perspicuity and compass of thought; though his speculations are deformed by an undue attachment to certain leading ideas, which, harmonizing with his habits of mind, had acquired an excessive preponderance in the course of his long and uncontroverted meditations. He possessed extensive knowledge, and his works bespeak a philosophical spirit; but their great and characteristic excellence proceeds from that glow of fresh and youthful admiration for every thing that is amiable or august in the character of man, which, in Necker's heart, survived all the blighting vicissitudes it had passed through, combining, in a singular union, the fervour of the stripling with the experience of the sage.

We subjoin a list of his writings, and those of Madame Necker. *Réponse à Morellet* (on the India Trade, 1769) *Eloge de Colbert*, 1773. *Sur le Commerce des Grains.* *Mémoires sur les Administrations Provinciales*, 1781. *Réponse*, (to Calon's accusation before the Notables, 1787.) *Le Compte Rendu.* *Nouveaux Eclaircissemens sur le Compte Rendu*, 1788. *De l'Importance des Opinions Réligieuses*, 1788. *Observations sur l'Avant Propos du Livre Rouge*, 1790. *Sur l'Administration de M. Necker, par lui-même*, 1791. *De la Révolution Française*, 1797.—By Madame Necker. *Des Inhumations Precipitées*, 1790. *Mémoire sur l'Etablissement des Hospices*, 1794. *Reflexions sur le Divorce*, 1795. And eight volumes of *Mélanges*, selected from her various unpublished writings.

NEDSJED. See Arabia.

NELSON, Horatio Viscount, was born 29th September, 1758, at Burnham Thorpe, a village in Norfolkshire, of which his father was rector. Catharine Suckling, the mother, was grand-daughter to an elder sister of Sir Robert Walpole; and to this connection Nelson owed the name Horatio, bestowed in honour of his god-father, the first Lord Walpole. To his mother it was farther owing, indirectly, that he adopted the profession of a seaman. From his earliest years, the boy had evinced a quickness of understanding, and a generous energy of spirit, which promised to raise him high in almost any department of human activity; it was the circumstance of Maurice Suckling, his uncle, being a captain in the British navy, which concentrated all those powers towards that single object, in prosecuting which Nelson acquired so lasting and hard-earned a reputation. He was only about twelve years old, when, being at home during the Christmas holidays, and happening to read, in a country newspaper, that Captain Suckling was appointed to command the Raisonnable of 64 guns, at that time put under commission in the prospect of a quarrel with Spain about the Falkland Islands, he instantly made known to his father, then at Bath, a strong wish "to go to sea with uncle Maurice." In consequence of a promise to provide for one of his brother-in-law's children, rather than from any choice in the proposed individual, Captain Suckling acceded to this request; and shortly after, Horatio took leave of North Walsham school, of William, his play-mate and brother, and set out for Chatham, where the ship was stationed.

It was early in the spring of 1771, that Nelson first set his foot on board of a king's ship. The reception was sufficiently disheartening. His uncle was not present at the time; no one had been apprised of the boy's coming; and he paced the deck for many hours without finding any person to receive or notice him. Nor did his subsequent experience soon belie the forebodings of so hard a commencement. A frame naturally delicate, and still more weakened by agues, was ill calculated to endure the physical hardships of a sailor's life,—the rough tumult of which was, moreover, sickening to a young and tender heart. Nelson felt wretched during the first years of his continuance at sea; and ever after retained a strong recollection of those early sufferings.

His situation was indeed uncomfortable; and the hopes of bettering it were distant and feeble. He did not sail in the Raisonnable, which was paid off, the dispute with Spain being settled; but he had already learned practical seamanship during a voyage to the West Indies in a merchant vessel; and undergone the fatigues and dangers of Captain Phipps' celebrated northern expedition, as cockswain in the Carcass; and gone out to India in the Seahorse of 20 guns, part of Sir Edward Hughes' squadron,—before his good conduct procured him even the rank of a midshipman: and about eighteen months after his arrival in India, a disorder attacked him, which resisted all the powers of medicine, and left no hope, except in an immediate return to Europe. His voyage home, it may well be supposed, was gloomy and desponding. Under the kind attentions of Captain Pigot, health was indeed slowly returning; but the anxiety and depression which frequently attend an affectionate melancholy character on entering upon active life, had ample means to prey upon him. "I felt impressed," he said, long afterwards, "with a feeling that I should neve rise in my profession. My mind was staggered with a view of the difficulties I had to surmount, and the little interest I possessed. I could discover no means of reaching the object of my ambition. After a long gloomy reverie, in which I almost wished myself overboard, a sudden glow of patriotism was kindled within me, and presented my king and country as my patron. Well, then! I exclaimed, I will be a hero! and, confiding in Providence, I will brave every danger."

From that time, a radiant orb, as Nelson expressed it, was suspended in his mind's eye, which urged him onwards to renown. Fortunate circumstances occurred to second this determination. His uncle had, in the interim, been made comptroller of the navy; on the 8th of April, 1777, Nelson passed his examination with credit for a lieutenancy; and next day, received a commission in the Lowestoffe frigate, then fitting out for Jamaica. His merits, and the interest he had now acquired, soon advanced him to a similar post in the Bristol flag ship, under Sir P. Parker; from this to be commander of the Badger brig; and next, on the 11th of June, 1779, to the rank of post-captain in the Hinchinbrook of 28 guns.

His services here, during General Dalling's expedition to Fort San Juan, in the isthmus of Panama, were such as to attract universal attention; but th climate, which had ruined the whole undertaking, well nigh proved fatal to him likewise; so that his appointment to the Janus of 44 guns, turned out a fruitless remuneration; and, to save his life, Nelson was obliged once more to return to England without delay.

Nelson's promotion, though hitherto comparatively speaking rapid, was far from keeping pace with the ardour of his character. Succeeding events were little calculated to sooth that impatience. His appointment to command the Albemarle, 28, in the North Seas, immediately after partial recovery from a tropical disease, accorded with his wants rather than his wishes; and when the ship was paid off, soon after the conclusion of the American war, he had still to seek consolation in the hope that "true honour predominated in his mind far above riches." A short visit to France quickly tired him of idleness; and (March, 1799,) he was glad to accept the Boreas, 28, ordered to the Leeward Islands as a cruizer on the peace establishment. His conduct on this station exhibited the same firmness and activity which had always distinguished him. By repressing the abuses and evasions of law, prevalent among the traders of that quarter, he acquired the esteem of all such as were fitted to appreciate the strong rectitude and bold decision of his character; but he acquired also the persevering hatred of numerous individuals whose peculations he had detected and exposed. Government *thanked* the commander-in-chief for what Nelson had done in direct opposition to his orders; the calumnies of his enemies preceded his return to England; and the Boreas, on arriving, was kept four months at the Nore, serving as a slop-ship. Nelson never stirred from on board; he performed the duty with strict and sullen faithfulness; and, on the 30th of November, 1787, when orders were received to pay off the ship, he said it was a joyful order, because it would release him for ever from an ungrateful service, with which he was unalterably determined never to engage any more. He would resign his commission instantly on reaching London.

The friend, to whom he spoke, wrote privately to Lord Home of the Admiralty, and prevented this passionate resolution from coming to effect. Nelson continued in the navy; and during the period of inactivity endeavoured to occupy his mind with rural pursuits at his father's parsonage of Burnam Therpe. A few months before he had married Mrs. Nisbet, a young lady, the widow of Dr. Nisbet, and niece of the President of Nevis, which latter had stood his warm friend in his disputes with the planters of the Leeward Islands. This connexion, long a source of deep enjoyment to him, helped to dispel the tedium of seclusion; the father was satisfied with the preferment, and delighted with the presence of his son; but the restless inquietude of Nelson's mind could not brook continued indolence, and this impatience was aggravated by the inattention of Government to his demands, and by menaced prosecutions on the part of his enemies in the West Indies, which on one occasion nearly induced him to forsake his country for ever.

After many fruitless, though earnest applications, he was at length gratified by an appointment to command the Agamemnon of 64 guns. This appointment, which ook place immediately after the commencement of our ate war with France, was procured by the interest of Lord Hood and the Duke of Clarence. The latter had known him and admired his talents, for a number of years; the former, whom he accompanied to the blockade of Toulon, had an early opportunity of estimating his worth, with which he was yet only acquainted by hearsay. The occupation of Toulon was soon discontinued; but in the reduction of Corsica, Nelson obtained, what he so greatly longed for, an occasion of showing his powers. He partly commanded the seamen employed in taking Bastia and Calvi, at the latter of which he lost his right eye; and, during the whole of those operations, his ardour and skill excited universal attention. His subsequent proceedings on the coast of Genoa were not less creditable to him; and the Austrian general, with whom he was appointed to co-operate, vainly attempted to impute, in the remotest degree, the results of his own misconduet, to misconduct on the part of his allies. Nelson was made a Commodore; obtained the entire confidence of Sir John Jervis, the new admiral; and contributed essentially to the great victory, which that officer gained over the Spaniards at Cape St. Vincent, on the 14th February, 1787. Naval men unanimouly assert, that a manœuvre which the Commodore executed at his own risk, with eminent peril and dexterity, was the main cause of our success on that occasion. Before the news reached England, he had been advanced to the rank of rear admiral; and his gallant conduct in the engagement was farther rewarded by the Order of the Bath.

Nelson's fame had long been high in the Mediterranean; it was now fast rising in his own country. The failure of an enterprise against Teneriffe, in which he lost the right arm, could not, when all things were considered, sensibly diminish this feeling; and his next achievement raised the admiration of his countrymen to enthusiasm, and gave him the character of a hero over all Europe. Early in 1798, Nelson (now Rear-admiral), his wound being cured after a short stay in England, proceeded in the Vanguard to Join Sir J. Jervis, now Earl St. Vincent, in the Tagus. He was soon dispatched, with a small squadron, to learn the object intended by the French expedition from Toulon. Being reinforced in the Gulph of Lyons by ten sail of the line, Sir Horatio proceeded towards Egypt in search of the enemy. His masts were seen from the French fleet near Malta, during a haze; and had Nelson been properly supplied with frigates, *eyes of the fleet* as he called them, while bitterly regretting their absence,—Buonaparte would probably have been captured in the beginning of his career, and Europe might have escaped its succeeding convulsions. As it was, Sir Horatio managed the pursuit with an eager sagacity, analogous to the boldness displayed in battle. The French had followed a devious track to Egypt, and he found them at last, on his second inspection of the Alexandrian coast, strongly moored across the entrance of Aboukir Bay.

About 7 o'clock in the evening of August 1, 1798, the English fleet moved forward to the attack. Admiral Brueys had previously expressed a private opinion, that the English missed him, because, not being superior in force, they did not think it prudent to hazard an engagement. The event fatally proved his mistake. In spite of his greater numbers, and his excellent position, the piercing intellect of his antagonist had already conceived its plan; before ten o'clock Brueys was dead; his ship l'Orient was blown into the air; the fleet which he lately commanded was totally ruined and dispersed.

On first beholding the French, Nelson had exclaimed, "a peerage or Westminster Abbey!" The better part of his anticipations was now fulfilled; he received the title of Baron Nelson of the Nile, with an annuity of £2000 per annum, and the general voice more than sanctioned this reward. From the scene of his victory, where crowds of Arabs and Egyptians filled the coast with rejoicings, to the remotest extremities of the civilized world, all who had been injured, or who feared injury at the hands of the French, blessed him as their saviour. The Neapolitan court received him with open arms; for a considerable period he took an active share in all their proceedings—in resisting the French invasion of their territory—in transporting the royal family to Palermo, and back again to Naples. They made him Duke and Feudatory of Bronte; his admirers would wish that such decorations had been all he acquired in their service. It is unnecessary to dilate upon the only stain that deforms the history of Nelson—his execution of Carraccioli, and his fervid, though pure attachment to Lady Hamilton. The former had the shew, not the substance, of justice; and the latter made his subsequent domestic life alternately a scene of bitterness and of rapture, in which the bitterness greatly prevailed.

We see him with more pleasure once again upon the ocean adding fresh laurels to his already glorious wreath. In the month of March 1801, Nelson, now promoted to be Vice-admiral of the blue, sailed towards the Baltic, for the purpose of checking the armed confederation entered into by Denmark, Sweden, and Russia, against the naval rights of Britain. For reasons which the public did not understand or relish, the first command was given to Sir Hyde Parker, and Nelson acted only in a secondary capacity. His advice was consulted, however, in all emergencies, and never deviated from without disadvantage. The time spent in negociation and other vacillating transactions, allowed the enemy to prepare their defensive works; this was galling to the mind of Nelson; but, on the second of April, he nobly redeemed all those errors of his coadjutors, before the batteries of Copenhagen. The battle was long and bloody, and several of our ships ran aground, and deranged the Vice-admiral's measures; Sir Hyde, who with a part of the fleet lay at a distance from the scene of action, even made the signal to retreat. The signal was indignantly neglected; Nelson gained the victory, and used it with a clemency suitable to the valour with which he won it. In order to stop the effusion of blood, he dispatched a letter to the Prince Royal of Denmark, for whom the contest was now become hopeless; and next day he went ashore, amid the murmurs and admiration of the Danish people, to settle the terms of an armistice, securing all the objects for which England had taken up the quarrel. He was soon appointed commander in chief in the Baltic, and his subsequent proceedings were equally spirited and decisive. Having, thuse effectually defeated the purposes of the northern confederacy, he returned home to enjoy the fresh renown with which those services had illustrated his name. Government exalted him to the rank of viscount; and the public followed him with an affectionate veneration, which few individuals have ever enjoyed in a nearly equal degree.

The next duty in which Nelson engaged was gratifying, rather as it proved the confidence which his countrymen reposed in him, than as it afforded room for the display of naval abilities. Immediately after his arrival, (July 1801) he was commissioned to guard the southern coast against the threatened French invasion. His attempt to cut out the shipping at Boulogne failed of success, not from want of skill in planning or of bravery in executing it, but from the untowardness of circumstances, which render boat-warfare at all times precarious. Two months after this event, the peace of Amiens delivered him from an employment to which his mind never felt any inclination.

But the greatest of his victories was yet behind. During the short continuance of peace, he had occupied himself chiefly in rural improvements at Merton, giving occasional attendance at the house of Lords, where his few speeches were no less remarkable for the correct information, than for the uprightness and integrity displayed in them. On the renewal of hostilities in 1803, he was instantly appointed commander in the Mediterranean. The principal duty of this post was to watch the movements of the large fleet lying in Toulon harbour. Nelson waited long and anxiously, till at length his tedious and strict watch was suspended by intelligence that Vice-Admiral Villeneuve had put to sea on the 10th January, 1805. Nelson steered for Egypt; but the enemy had returned to port. They again sailed on the 31st March: and the sagacity with which he divined their intentions, the rapidity with which he pursued them from Europe to the West Indies, and from the West Indies back again to Europe, are unrivalled in the records of naval history. The terror of his name had saved our colonies; and Villeneuve's fleet returned home, with all possible speed. Nelson too returned home, but it was only to enjoy a brief respite from fatigue. In August, news arrived that Villeneuve was at Cadiz, and Nelson immediately volunteered to go and meet him. The English fleet kept out at sea to hide their force, and Nelson's arrival was not known to the combined armament,—when, on the morning of October 19th, the signal was given that the enemy were coming out of port. After a variety of movements, the contending fleets came in sight of each other near cape Trafalgar, at day-break on the 21st. The details of a sea-fight are not often interesting to general readers; but the victory which terminated the illustrious career of Nelson was so striking in its acquisition, so important in its consequences, that a few particulars respecting it seem worthy of remembrance.

"Soon after day-light, Nelson came upon deck. The 21st of October was a festival in his family, because on that day his uncle, Captain Suckling, in the Dreadnought, with two other line of battle ships, had beaten off a French squadron of four sail of the line, and three frigates. Nelson, with that sort of superstition from which few persons are entirely exempt, had more than once expressed his persuasion that this was to be his day of battle also; and he was well pleased at seeing his predictinn about to be verified. The wind was now from the west,—light breezes with a long heavy swell. Signal was made to bear down upon the enemy in two lines, and the fleet set all sail. Collingwood in the Royal Sovereign, led the lee line of thirteen ships; the Victory led the weather line of fourteen.

"Blackwood went aboard the Victory about six. He found Nelson in good spirits, but very calm; not in that exhilaration which he had felt on entering into battle at Aboukir and Copenhagen: he knew that his own life would be particularly aimed at, and seems to have looked for death with almost as sure an expectation as for victory. His whole attention was fixed upon the enemy. They tacked to the northward, and formed their line on the larboard tack, thus bringing the shoals of Trafalgar and St. Pedro under the lee of the British, and keeping the port of Cadiz open for themselves. This was judiciously done; and Nelson, aware of all the advantages which it gave them, made signal to prepare to anchor.

"Villeneuve was a skilful seaman, worthy of serving a better master and a better cause. His plan of defence was as well conceived and as original as the plan of attack. He formed the fleet in a double line, every alternate ship being about a cable's length to windward of her second, a-head and a-stern. Nelson, certain of a triumphant issue to the day, asked Blackwood what he should consider as a victory. That officer answered, that considering the handsome way in which battle was offered by the enemy, their apparent determination for a fair trial of strength, and the situation of the land, he thought it would be a glorious result if fourteen ships were captured. He replied, "I shall never be satisfied with less than twenty." Soon afterwards, he asked him if he did not think there was a signal wanting. Captain Blackwood made answer, that he thought the whole fleet seemed very clearly to understand what they were about. These words were scarcely spoken before the signal was made, which will be remembered as long as the language, or even the memory of England shall endure;—Nelson's last signal:—"England expects every man to do his duty." It was received throughout the fleet with a shout of answering acclamation, made sublime by the spirit which it breathed, and the feeling which it expressed." "Now," said Lord Nelson, "I can do no more: we must trust to the great Disposer of all events, and the justice of our cause. I thank God for this great opportunity of doing my duty."

"He wore that day, as usual, his Admiral's frock-coat, bearing on the left breast four stars of the different orders with which he was invested. Ornaments which rendered him so conspicuous a mark for the enemy, were beheld with ominous apprehension by his officers. It was known that there were riflemen on board the French ships; and it could not be doubted but that his life would be particularly aimed at. They communicated their fears to each other; and the surgeon, Mr. Beattie, spoke to the chaplain, Dr. Scott, and to Mr. Scott the public secretary, desiring that some person would entreat him to change his dress, or cover the the stars; but they knew that such a request would highly displease him. "In honour I gained them," he said, when such a thing had been hinted to him formerly, "and in honour I will die with them." Mr. Beattie, however, could not have been deterred by any fear of exciting his displeasure from speaking to himself upon a subject in which the weal of England, as well as the life of Nelson was concerned, but he was ordered from the deck before he could find an opportunity. This was a point upon which Nelson's officers knew that it was hopeless to remonstrate or reason with him; but both Blackwood, and his own captain, Hardy, represented to him how advantageous to the fleet it would be for him to keep out of action as long as possible; and he consented at last to let the Leviathan and the Temeraire, which were sailing a-breast of the Victory, be ordered to pass a-head. Yet even here, the last infirmity of this noble mind was indulged; for these ships could not pass a-head if the Victory continued to carry all her sail; and so far was Nelson from shortening sail, that it was evident he took pleasure in pressing on, and rendering it impossible for them to obey his own orders. A long swell was setting into the bay of Cadiz: our ships, crowding all sail, moved majestically before it, with light winds from the south-west. The sun shone on the sails of the enemy; and their well formed line, with their numerous three-deckers, made an appearance which any other assailants would have thought formidable; but the British sailors only admired the beauty and the splendour of the spectacle; and, in full confidence of winning what they saw, remarked to each other, *what a fine sight yonder ships would make at Spithead!*"*

A few minutes before twelve o'clock, several French ships a-head of the Victory began to fire single guns at her, to ascertain the distance. When Nelson saw the shots pass beyond him, he desired Blackwood and captain Prowse, of the Sirius, to repair to their respective frigates; and as the former took leave, expressing a hope that he would soon return, and find the commander in possession of twenty ships, Nelson squeezed his hand, and said "God bless you, Blackwood! I shall never see you more."

Collingwood's line was first engaged: Nelson, steering about two points nearer the north, soon after received a single shot through his main-top-gallant sail; on observing which, the enemy immediately opened their broadsides, aiming chiefly at the rigging, in order to disable the Victory, before she could close with them. They had also planted riflemen in the shrouds; and by those means, considerable havoc was made among Nelson's men, before he could run on board the Redoutable; in his way to which he passed near the bows of an "old acquaintance," the Santissima Trinidad, memorable for the attack he had made on her long ago at Cape St. Vincent's. The Redoutable received him with a broadside, and then instantly let down her lower deck-ports, in fear of being boarded through them. She used her great guns no more, though the Victory kept up a tremendous fire on all sides, her larboard shot striking the Santissima Trinidad, and Villeneuve's ship, the Bucentaure; while Captain Harvey, in the Temeraire, had also, on the opposite quarter, come alongside the Redoutable,—which was thus placed between him and Nelson, the Temeraire herself having, in like manner, another enemy close to leeward. Of the four ships thus fearfully commingled, the two British alone made use of their cannon; they fired with a diminished charge in the lower guns, lest one might transmit her shot to the other; and the fireman of each gun stood ready with a bucket of water, to dash into the hole where a ball entered, to prevent the timber from inflaming. The French, again, trusted to their riflemen, by whose efforts, though the battle could not be gained, it might be rendered bloodier to their opponents. Nelson had always despised this mode of warfare, which he looked upon as dastardly and indecisive; yet the destruction it occasioned could not make him forget the dictates of humanity, and he twice ordered his firing to cease, supposing the Redoutable, which carried no flag, to have struck, as her great guns were silent. It was to this ship that he owed his death. In the heat of the action, about a quarter past one, a musket ball* from her mizen-top, which was not then above fifteen yards from him, struck the epaulette of his left shoulder; and he fell prostrate, on the spot still wet with the blood of Mr. Scott, his secretary, who had been struck down at his hand before the Victory's firing commenced. Nelson felt that he was mortally wounded, and said so to Hardy; yet such was his composure, that, having observed the tiller-ropes to be shot away, he stopped the men who were carrying him down to the cock-pit, and gave orders to repair the damage; and then took out a handkerchief to cover his face and stars, that he might not be noticed by the crew.

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* Southey's Life of Nelson, vol. ii.

On reaching the cock-pit, which was crowded with wounded and dying men, Nelson desired the surgeon to leave him, and attend to others for whom his services might be useful. He was laid on a pallet, and all that could be done for him was to fan his face, and give him frequent draughts of lemonade to allay the death-thirst. He lay in great pain, but this bodily pain extended not to his mind. The Victory's crew cheered loudly as often as an enemy struck: and at each cheer a gleam of pleasure was observed to illuminate his countenance. It was about an hour, before Hardy, for whose appearance he had now got very impatient, could come down to him. They shook hands in silence; Nelson inquired how the day went; to which Hardy answered, that ten ships had already struck, and more were likely to follow them. Nelson again shook hands with him, and sent him upon deck, from which in about fifty minutes he once more returned to sooth the dying moments of his commander, with intelligence of a complete and signal victory: fifteen ships at least had struck. "It is well," said Nelson, "but you know I bargained for twenty."† With a greater emphasis he bade Hardy anchor: then said in a lower tone, that he wished to be buried near his parents; and solemnly charging this affectionate and agitated friend with the care of Lady Hamilton,‡ he took farewell of him for ever. Soon afterwards his articulation became difficult; he was, however, distinctly heard to whisper, "Thank God, I have done my duty!" He repeated the words oftener than once, and never uttered more. The last gun was fired at the enemy about two minutes before he departed—with great calmness, three hours and a quarter after being wounded.

The victory of Trafalgar, the greatest ever gained, completed the fabric which a succession of brave men, since the time of Queen Elizabeth, had been slowly rearing with their toils and their blood. It stamped with increased importance and durability, as it were, the deeds of our Drakes, and Frobishers, our Blakes and Benbows; and rendered the English flag indisputably triumphant in every sea. The man at whose expense it was purchased, and as we thought dearly purchased, had merited to stand at the head of such a list. His life was a series of triumphs nobly earned by the unremitting exertion of a mind, gifted with the most acute penetration, the loftiest ardour, the most inflexible determination; and the last scene of it was fitly, though mournfully adapted to its general tenor.

But in estimating the character of Nelson, a defective judgment would be formed, were he viewed only as a great captain. Whoever inspects his history minutely, will find in it traces of a spirit possessing a higher and more general species of excellence. His mind, it is true, was not unfolded by personal education, or by intercourse with cultivated men; his understanding turned almost exclusively on naval tactics; his enthusiasm was bent towards the attainment of naval honour; his sense of rectitude embodied itself in a feeling of loyalty to the King of England, and of hatred to all Frenchmen. Yet the high powers of genius existed in him, less palpably indeed, but not less certainly, for being obscured and distorted by his professional habits. The quick intellect was there, the fervid imagination, the keen susceptibility nourished by it—and contributing to impart that force of will, which nothing could oppose. As a necessary consequence, there was also the restless inquietude which great objects alone, and those but for a time, could satisfy or assuage. Now and then this latter peculiarity might be unpleasantly manifested: in vulgar natures it would have been named discontent; but with him it was the impulse to generous feeling and daring enterprise.

Melancholy experience has never ceased to shew that great warlike talents, like great talents of any kind, may be united with a coarse and ignoble heart. But in Nelson, the sterner qualities of a conqueror were embellished by all that is elevated in a sense of honour, and tempered by all that is soft and romantic in human affections. Time has abated the first glow of our admiration for his exploits; exploits of a more exciting character have occupied men's thoughts, and cast his glories partially into the shade; the period is advancing, when the naval superiority which he completed will pass away: but Nelson's name will always occupy a section in the history of the world, and be pronounced, wherever it is understood, as that of a Hero.

NEOT'S, St. a market town of England in the county of Huntingdon, is pleasantly situated on the north bank of the river Ouse, which is crossed by a stone bridge, which connects the town with the village of Eynesbury. The town, which is large and well built, consists of three principal streets. The church, which is a handsome building, in the pointed style of Henry VIIth's reign, has an elegant tower 150 feet high. The windows are large, and contain panes of painted glass. By the river Ouse St. Neot's enjoys a communication with most parts of the kingdom. Its trade consists chiefly in the importation of coals and groceries. Population 370 houses, and 1,752 inhabitants. See the *Beauties of England and Wales*, vol. vii. p. 567.

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* The man who fired it did not live to boast of his success. Being observed by an old quarter-master, he was again easily recognised from his glazed cocked hat and white frock, when but himself and another remained alive in the Redoutable's shrouds. The quarter-master, standing beside two midshipmen, was also killed by him, whilst crying out eagerly, "that's he! that's he!" and next moment the rifleman was, in his turn, shot through the head and heart at once by those two officers.

† It is somewhat remarkable that twenty was the actual number that surrendered, though, owing to unfavourable circumstances, only four of them could be saved.

‡ Lady Hamilton's name was again mentioned to the chaplain, with a memento that he left her, and Horatia Thomson Nelson, (a child whom he now acknowledged for his daughter), as a legacy to England. While in sight of the enemy, he had that morning written a memorial earnestly recommending both to the gratitude of his country; and it was a singular proof of his devotedness to Lady Hamilton, that her image was ever present with him throughout the whole of a day so awful. She repaid this affection unworthily—detestably, as it seemed—by publishing his correspondence with her, some years afterwards. But her friends allege that she was *driven* to this base step, as government gave no ear to Nelson's last request, and she became involved in pecuniary difficulties. Her straights may perhaps extenuate, but cannot justify this proceeding, which, on any supposition, bears too indubitable marks of that intriguing mercenary spirit, which this large-minded woman had acquired in her progress from the low station of an opera girl, to that of an English gentleman's widow, and an English hero's "Guardian Angel."

NEPAUL, an extensive independent sovereignty in India, comprehends nearly the whole of Northern Hindostan. Its territories, including the tributary provinces, are situated principally between the 27th and 32d degrees of north latitude, stretching in length from north-east to south-west, about 700 miles, and 100 at the average breadth. On the east they are bounded by the possessions of the Deb Rajah of Bhootan, from which they are separated by the river Teesta; on the south-east by the Morung hills, which divide them from the Bengal districts of Betwee, Hazary, &c.; and, on the north-east by the alpine ridge of Kuchar, which forms the frontier of Thibet. On the south, they are bounded by the British districts in Bengal, Bahar, Oude, and Delhi. On the west, since the conquest of Serinagur in 1803, by the Nepaulese, the river Sutelege separates these territories from those of Lahore. Along the whole of the northern frontier, the great chain of the Himalaya mountains divides them from the table-land of Tibet. But it is only a small part of this extent which is properly denominated Nepaul. This appellation is limited to a valley of an oval figure, above 50 miles in circumference, bounded by stupendous mountains on the north and south, and on the east and west by less elevated ridges. The bottom of the valley is calculated to be at least 4000 feet above the level of the sea, and the highest of its nearest mountains on the north at 4000 more. The most elevated of these, named Sheopuri, gives rise to the rivers Bhagmatty and Vishnumatty, which, with many other streams, traverse the valley, and fertilize its fields. The surface of this inclosed spot is very uneven, intersected with deep ravines and studded with little hills. In the ancient Hindoo books it is called Deccani Tapoo, or the southern isle, in reference to its situation with respect to the Himalaya mountains, and is described as originally an immense lake, which, within the progress of ages, had retired within the banks of the Bhagmatty, or, according to other accounts, was evacuated by the present channel of that river, which one of its former sovereigns caused to be opened through the southern ridge of mountains.

The ancient history of Nepaul is involved in mythological fables, and represents this secluded valley as one of the favourite haunts of the Hindoo deities. The first of its princes of whom a chronological list is preserved, was Nymuni, who communicated his name to the valley, and whose dynasty continued to reign about 500 years. Various succeeding dynasties are detailed in the national traditions, but the periods assigned to the respective reigns are obviously extended far beyond the ordinary course of human life, and utterly unworthy of credit. Amidst these revolutions and changes of masters, however, it does not appear to have ever fallen under any of the great Asiatic powers, but to have been subjected by internal usurpers, or adjacent invaders. In A. D. 1323, Kurr Sing Deo, Rajah of Semroun Ghur, being driven from his own possessions in Oude by the Patans, completely subdued Nepaul, and retained the crown in his family till the year 1768, when Purthi Narayon, Rajah of Ghoorka, who had been invited into the country as an ally, made himself master of the kingdom. In 1769 an attempt was made by the British government to re-instate Runjeet Mull, the dethroned sovereign, who had taken refuge in Benara, and a military force was sent, under Captain Kinloch, into Nepaul, which penetrated as far as Sedowly; but the sickliness of the troops occasioned the enterprise to be abandoned, and the usurper in the end made new additions to his dominions. He was succeeded in 1771 by his son Singh Pertaub, who extended the empire considerably towards the south-west, and died in 1775. His brother, Bahadur Shah, acting as regent, subdued, in like manner, all the state towards the west, as far as Serinagur. About the year 1790, the Nepaulese, having repeatedly invaded and plundered the Lamas of Tibet, were attacked by a numerous Chinese army, and compelled to become tributaries to the Emperor of China. The court of Nepaul, in the first alarm occasioned by this invasion, had requested the aid of the British government in India, and Captain Kirkpatrick was dispatched by Lord Cornwallis, in 1793, to mediate between the two powers; but the Nepaulese having submitted before his arrival, his endeavours were directed to the establishment of a commercial treaty between the Ghoorkali and the East India Company, which had already been commenced by Mr. Duncan, when resident at Benara. The extreme jealousy of the Nepaulese, however, frustrated all his endeavours, and it was not till the year 1801 that a friendly alliance was formed between the two governments. In order to carry into effect the provisions of this treaty, and to promote other negociations between the Governor-General and the Nepaul Rajah, each agreed to depute a confidential person to reside as envoy with the other.

The country between Catmandoo and the eastern frontiers is almost entirely mountains, and gives rise to a number of rivers. On the western side, south of Kettowra, and around that place, the country is composed of hills confusedly heaped together, and separated in various directions by narrow glens. This is the general appearance of the mountainous districts in Nepaul, as no uninterrupted range occurs, after passing the Cheriaghauti ridge on the south-east quarter of the empire. The sides of the hills are every where covered with lofty trees, chiefly of the saul or sessoo, or partially cultivated with the different sorts of grain. Along the whole of the southern boundary, stretching from the Teesta to Serinagur, is the great forest, about ten miles deep, which contains a great quantity of excellent timber, which forms a considerable article of traffic, even to the distance of Calcutta. This tract is a low marshy district, called Teony or Turryani, a name which is sometimes also applied to the flats below the hills in the interior parts of Nepaul, where the heat and moisture are apt to produce an infectious fever called the Owl. The seasons of Nepaul are much the same as in the upper parts of Hindostan; but the rains commence a little earlier, setting in from the south-east, and are usually very copious till towards the middle of October. During this period the torrents are often extremely violent, and sometimes occasion injurious inundations. Though the northernmost of the valley of Nepaul scarcely reaches a higher latitude than 27½ degrees, yet the climate is equally temperate with some of the southern countries of Europe. During winter, the tops of the mountains are sprinkled with snow for several days together; and the cold is occasionally sufficiently intense, during the space of three or four months, to freeze the pools of standing water. From the 7th to the 25th of March, the thermometer was usually between

50° and 54° a little after sun-rise, between 81° and 84° about noon, and between 62° and 66° in the evening. But the inhabitants of the valley, by ascending the sides of the surrounding mountains, may pass at pleasure, in the space of a few hours, through a variety of temperatures; and, in a few days, may exchange a heat equal to that of Bengal for the cold of Russia. On this account, it is considered that a short residence in the country of Nepaul, which affords so many varieties of temperature, might supply to invalids in India all the benefits of a voyage to Europe. The more elevated valleys are highly salubrious, as far as can be judged from the healthy appearance of the inhabitants. The lower valleys only are subject to fever; but, in several places, guttural tumours, resembling the goitres of Europe, prevail among the natives, which they ascribe to an insect in the water, or to some mineral impregnation.

Nepaul contains excellent copper and iron mines; and some veins of silver are said to have been discovered; but these are supposed to have been nothing more than specimens of galena or lead ore, some of which are very rich, and well worth the working. In the western districts, arsenic and pyrites are abundant; but the government has desisted from working the sulphureous ores, on account of the deleterious effects of the operation. Except a few grains procured from the sand of the rivulets flowing through the territory, the country of Nepaul does not yield any gold; and the quantities of the metal imported into Bengal by the inhabitants, were procured by them from Thibet in exchange for goods. No volcanoes have been observed in the country by European travellers; but some eruptions are said to have taken place in the western districts. There is a great variety of stones, adapted for the purposes of building, and several kinds both of marble and jasper. Limestone and slate abound every where; but instead of the former the natives employ a kind of mud, as cement. Many curious natural grottos, full of crystals and calcareous incrustations, are scattered over this romantic country; and a considerable mass of rock-crystal is said to exist in the vicinity of Goorkha. But the mineralogy of Nepaul is only so far known as to prove, that many interesting objects remain to be discovered in that department of knowledge.

The native vegetable productions of Nepaul are very numerous and valuable. The northern mountains are covered with the different kinds of Alpine plants; and the country is in a manner overrun with flowering shrubs, aromatic herbs, medicinal plants, and dyeing stuffs. Among its spontaneous productions are several edible roots and herbs, particularly a species of yam called tooral, and a kind of wild asparagus named kurraila, besides many others, which form the principal subsistence of the poorer inhabitants. The peach, the raspberry, the walnut, the mulberry, grow freely without culture; and it is supposed that, with proper attention all the fruits and esculent vegetables of England might be successfully raised in the country.

The soil under cultivation generally produces from twenty to thirty fold, and yields two or three crops in the season. Many spots produce one of rice, one of wheat or pulse, and one, or even two, of a useful vegetable called tori. Some grounds yield two crops of rice in succession, (one fine and the other coarse) besides affording, in the same year, a crop of wheat. Several kinds of dry rice, called ghya, are raised in situations exposed to falls of snow; and others flourish in the loftiest and driest spots, without being flooded at all. It is conjectured that some of these kinds might succeed in England. The sugar-cane is cultivated profitably in some districts, but only for the consumption of the grower. The ground undergoes repeated ploughings, and the expense of agricultural operations appears to be considerable. In Nepaul Proper, where the inhabitants have too much reverence for the bullocks to employ them in labour, the plough is little used; and the fields are prepared for the rice by digging with a sort of spade. The sovereign is considered as the absolute proprietor of all the lands; and even the highest subject has a very precarious hold of his possession, which may be exchanged for others, or taken from him entirely, at any meeting of the grand council, which consists of the principal officers of government, and such other persons as the sovereign may think proper to invite. The prince has extensive crown lands in almost every district, which he farms out to others, or which are cultivated by husbandmen, with whom he equally divides the produce, or which he puts under the care of agents, who require the neighbouring husbandmen to dedicate so many days of every year to their tillage. Other lands are given in grants, and are rent-free, saleable, and hereditary; but a considerable sum is paid at the original investiture of the proprietors, which must be renewed under every succeeding prince, and occasional presents are at the same time expected. To the proprietors, or jaghieredars, the husbandmen usually pay, as rent, a part of the produce, or a certain cess, according to the number of his ploughs or spades. Usually one half of the produce, or one quarter, and so many maunds of oil of sissoo, is paid as rent, while the cultivator bears all the expense of tillage.

Wild beasts are not very numerous in the country, except in the extensive forests towards the south and south-west frontiers, where numbers of elephants, rhinoceros, and tygers are found. The former sometimes issue from the forests in droves, and overrun the cultivated tracts to a considerable distance. The musk-deer is common in the northern districts, and is usually caught by means of a snare. Monkeys are abundant in many places, particularly in some of the sacred groves, where they are regarded as emblems of the deity, and are protected with the utmost reverence. The chowri, a species of cow, whose beautiful tail is an article of export; and the changra or shawl goat, though both are properly natives of Thibet, are frequently met with in the Kuchar mountains. The animal known by the name of the Nepaul dog, (properly also a native of Thibet) is a fierce surly creature, about the size of an English bull-dog, and covered with long thick hair; but they are so celebrated as watch-dogs, that the Chinese army, in their progress through the country, are said to have employed them as sentinels on the picquets around their camp. The feathered tribe are not supposed to be numerous among the mountains: the most remarkable are the pheasant species, some of which are extremely beautiful The ortolan, wild goose, wild duck, and several other birds, common to the countries south of Nepaul, are occasionally seen in the valleys; but they are considered as only visitors on their passage between Hindostan and Thibet. Many of the rivers swarm with fish; but the water is so transparent, and the streams so rapid, that angling is impracticable; and they are taken chiefly by means of nets stretched across to intercept the shoals, when the fishermen dive among them even in shallow water, and seize them with their hands or teeth. The cattle of Nepaul are not much superior to those usually met with in Bengal, and the upper provinces; but the herds, which are fed in some of the less cultivated valleys, are very sleek and plump, and yield the richest and sweetest milk in the world. The horses chiefly used for riding, are the Tangun or Tangustan breed, from a mountainous district in Thibet, a small but strong and spirited animal, most indefatigable in climbing, and almost infallible in descending the steepest and roughest roads.

The government of Nepaul, like that of most Asiatic countries, is essentially despotic, but modified by certain observances enjoined by immemorial usage, and which the most powerful monarch cannot safely disregard. The sovereign is partly controlled by a kind of aristocratic body of chiefs, but not upon any principles favourable to the great mass of the subjects. The principal officers of state are the Choutra, or the prime minister, who is invariably a relative of the rajah, whose office is that of a kind of comptroller-general over all the inferior departments of administration; the Kajees, four in number, but one of whom only acts, whose business it is to superintend the revenue, and discharge the duties of public treasurer; the Sirdars, who generally command the armies, and direct the military arrangements; the Khurdars, who are two in number, and act as secretaries, preparing all the dispatches of the sovereign, and attending the deliberations of the council; the Khupperdar, who has the charge of the Rajah's private wardrobe, jewels, and kitchen; the Khuzanchee, who issues all public disbursements, and directs the public wardrobe. Besides these six officers, who are considered as the principal administrators of government, and therefore named Bhardars, or "bearers of burdens," there are the Ticksali, or superintendant of the mint, who also levies all duties or imports from Thibet; the Dhurma Udhikar, or chief criminal judge, whose sentences, however, must be approved by the Rajah, as those of the inferior judges must be by the chief judge; the Bicharies, four in number, and usually Brahmins, who are judges of all civil questions, but still with a reservation of the Rajah's approbation; the Dittha, or superintendant of police; the Jaitha Boora, or senior, who is employed on temporary or complimentary embassies; the Soubahs, or governors of districts and government collectors; the Omrahs, or commanders of military posts, who are generally of the Rajepoot tribe, independent of the civil governors, and whose troops are raised by themselves among their own kinsmen. The basis of the civil and criminal jurisprudence of Nepaul, as of most other Hindoo states, is the Dhurma Shasta, the criminal branch of which is said to be administered with considerable integrity; but the civil department is so defective, that the late regent, Bahadur Shah, is said to have once intended to apply to the East India government for a code of laws.

The Nepaul territories being for the most part parcelled out in Jaghires, or grants, the proportion of their produce received into the treasury is by no means considerable; and the amount of the whole revenue of government is not supposed to exceed 30 lacks of rupees per annum. It arises chiefly from profits on the sale of elephants; duties on exports, and the imports of gold and silver from Thibet; the mint; profits on salt-petre, copper and iron mines; duties on salt, and the land-tax. But, as the heaviest charges of government, both civil and military, are defrayed by jaghires, or assignments of land, and as the court does not on any occasion affect great splendour, the receipts are considered as fully adequate for the expenditure; which consists chiefly in the purchase of jewels, silks, and cottons, fire-arms, military stores, and clothing for the regular troops.

The regular troops consisted, in 1793, of 50 or 60 companies of unequal strength, but containing on an average 140 fire-locks, each commanded by a jubadan, with an undeterminate number of jemadans and other officers under him. They are clothed and disciplined in a very slovenly manner; but are brave, tractable, and capable of enduring great hardships. The rajah's guards are distinguished from the other companies only by having more officers, and carrying the war-standard, which exhibits, on a yellow ground, an embroidered figure of the monkey god Hunniman. The artillery, for which the face of the country is not at all adapted, is very inefficient. The irregular militia, enrolled under the omrahs, are pretty numerous; and, besides match-locks, are armed with bows and arrows and hatchet swords.

The religion of Nepaul in general resembles the Hindoo tenets established in other parts of India; and, from the secluded nature of the country, has been preserved in a state of superior purity. The valley of Nepaul particularly abounds with temples of great sanctity; and almost every fountain, river, or hill, is consecrated to some one or other of the Hindoo divinities, of whom nearly 3000 are worshipped within its limits.

The commerce of Nepaul is neither so extensive nor beneficial as it might be rendered by proper regulations. The ignorance and jealousy of the government, together with certain monopolies, prevent a free prosecution of trade between Thibet and the East India Company through the channel of Nepaul, which might prove highly beneficial to all parties. At the same time considerable protection is afforded to foreign merchants resident in the country. The principal exports to British India are, elephants, elephants' teeth, rice, timber, hides, ginger, terra japonica, turmeric, wax, honey, resin, walnuts, oranges, long-pepper, ghee, bark of the root of bastard cinnamon, dried leaves of ditto, large cardamums, damma, lamp-oil, and cotton of the simul tree. Besides these articles, which are the produce of the country, various commodities from Thibet are transferred in the trade with India, particularly small horses, sheep, goats, and other domestic animals, gold dust and grains, salt, sulphur, antimony, arsenic, musk, and several medicinal drugs. The imports from the Company's dominions into Nepaul, either for the consumption of that country, or for the Thibet market, are Bengal cloths, muslins, silks of various sorts, raw silk, gold and silver laces, carpets, British cutlery, saffron, spices, sandal-wood, quicksilver, cotton, tin, lead, zinc, soap, camphor, tobacco, and coral.

The inhabitants of the valley fabricate a coarse cotton cloth, for home consumption; and make paper from the bark of certain trees. They work well in copper, iron, brass, &c.; and export to the south some of their brazen utensils. Their cutlery, such as swords, daggers, &c. is good; but they have not succeeded in an attempt to manufacture fire-arms. They gild exceedingly well; and construct bells of so large a size as five feet in diameter. They are very ingenious in carpentry, though they never use a saw, but divide their wood, of whatever size, by the chissel and mallet. They make a little salt and salt-petre, but not equal to that of Thibet. They also distil spirits from rue and other grains, and prepare a strong fermented liquor from wheat, &c. The currency consists chiefly of silver pieces of eight annas, called a mohr, or of sixteen annas, called a sirca. They have a coin of so low a value as the 288th part of a sicca. There are rupees, and some very small coins of gold struck at the mint; but these are employed rather as medals and presents than as current coin. There are likewise copper coins, 36 of which are equal to one mohr.

The principal towns of Nepaul are, Catamandoo, or Khatmandû, Patn, Bhatgoug, Kirthipoor, within the valley; and Gorcah, Jemlah, Almora, and Serinagur, in the other districts. The first of these, though surpassed by some of the others in size and appearance, is counted the capital, as being the residence of the Rajah. It stretches along the east bank of the Bishnmutty river about a mile in length, and seldom extending above half a mile in breadth; and is chiefly remarkable for the multitude of its wooden temples. The houses are built of brick and tiles, (which are of excellent quality,) and are three or four stories in height, but generally of a mean appearance. The streets are narrow and filthy; and the number of inhabitants, including those of the dependent villages, is estimated at 50,000. The town of Kirthipoor made so obstinate a resistance to the Goorkhali in his reduction of the country, that he commanded all the men's noses to be cut off; and, in derision of the unhappy sufferers, ordered the name of the place to be changed into Nascatapoor, "the town of men without noses." The population of the valley alone is reckoned at no less than half a million, but the rest of the country is by no means so closely peopled.

The inhabitants of this country consist chiefly of the superior classes of Hindoos, (Brahmins, and Khetrees, with their various subdivisions,) and of Newars, Dhenwars, Mhanjees, Bhootias, and Bhanras. The former of these, (who compose the army of the state, and engross all situations of trust, whether civil or military,) are found dispersed promiscuously throughout the country. The Newars are confined almost entirely to the valley of Nepaul Proper. The Dhenwars and Mhanjees are the husbandmen and fishers of the western districts. The Bhootias, generally speaking, occupy such parts of the Kuchar ridge as are in the dominions of Nepaul. The Bhanras are a sort of separatists from the Newars, and have conformed to the Bhootias in the custom of shaving their heads, and many other idolatrous rites. To the eastward, some districts are inhabited by various uncivilized tribes of the lowest Hindoo castes, but of whom little more is known except the names. The principal are the Kerrauts, the Hawoos, the Limbooas, and Miggerkootees.

As Nepaul has been ruled for many centuries by princes of the Rajepoot tribe; and as the various classes of Hindoos appear to have, at all periods, composed a great part of its population, there is a very general resemblance in manners and customs between this part of the inhabitants and their kindred sects in the adjacent provinces of Hindostan. They are, probably, the only Hindoo people who have never been disturbed by any Mussulman power. They are distinguished by a striking and universal simplicity of character, which appears in all classes, and in all their modes of life. They are free from all ostentation or parade in public or private life, and discover great suavity of deportment, ease, and frankness, and, apparently also, a superior integrity of conduct to the more polished and wealthy inhabitants of southern India. Even among themselves, the lower orders are permitted to use considerable freedom in their carriage and conversation, in the presence of the superior orders; and a private soldier, addressing the highest officer, or a poor fisherman, approaching a governor, delivers his sentiments without any backwardness or embarrassment; but, at the same time, without any degree of rudeness or disrespect. The Newars differ considerably from the other Hindoo natives in character, customs, language, and religious rites, particularly in feeding on the flesh of buffaloes; and appear to be an insulated race of people, whose origin cannot be traced to any of the nations immediately surrounding, but who are conjectured to have sprung from a Tartar or Chinese stock. They are not supposed to have been at any period of a warlike disposition, and are rarely employed in the army; but are almost exclusively engaged in the agriculture, arts, and manufactures of the country. They are, in general, of a middle size, with broad shoulders and chest, stout limbs, round flat faces, small eyes, low, and somewhat spreading noses, open and cheerful countenances. They possess great corporeal strength, and are capable of severe labour, particularly in travelling as hill porters under heavy burdens. Their complexion is between a copper and sallow colour. The women have sometimes a little florid tint on the cheek; and it is remarkable that, like the females among the Nairs of Malabar, they may have as many husbands as they please, with the power of divorcing them on the slightest pretences.

The pundits of the country are not inferior to those of any other Hindoo district, in the branches of science usually cultivated among them. Their favourite study is astronomy, or rather judicial astrology, to which, indeed, all ranks are strongly attached, and by which almost all their proceedings, both in public and private life, are chiefly directed. It is supposed that ancient and valuable Sanscrit manuscripts, in every department of Brahminical learning, are more likely to be found in the valley of Nepaul, particularly at Bhatgong, than in any other place in India. Besides the Sanscrit, which is cultivated by the Brahmins, several vernacular languages are spoken by the different tribes which have been mentioned. See *Asiatic Researches*, vol. ii.—Turner's *Embassy to Thibet.*—Kirkpatrick's *Account of the Kingdom of Nepaul.*—And Dr. Francis Buchanan's *Account of Nepaul.* (*q*)

NEPTUNE, the son of Saturn and Ops, and the brother of Jupiter, Pluto, and Juno. He was devoured by Saturn on the day of his birth, but was restored by means of a potion administered by Metis. Along with his brother Neptune he shared the empire of Saturn, and received the kingdom of the sea as his portion. A full account of his fabulous history and attributes will be found in Spence's *Polymetis*, p. 65, 215, &c. and in Lempriere's *Classical Dictionary*, Voc. Neptune.

NERO. See Rome.

NERVA. See Rome.

NESS, Loch. See Inverness-shire, and Navigation Inland, in this volume.

NET. An account of a new machine for weaving fishing-nets will be found in our article Chainwork.

NETHERLANDS, The, or Low Countries, so called from their position with regard to several great rivers, and the general aspect of their surface, consist of seventeen provinces, which, together with the Grand Duchy of Luxemburg, now form a kingdom on the western coast of Europe. For nearly the last two centuries, the name Netherlands has been somewhat vaguely applied. Occasionally it has been restricted to the ten southern provinces, which it is usual at present to distinguish by the title *Belgic*; the seven northern provinces having at the same time been known by the appellation of *Dutch Republic*, or *United Provinces*. Under the article Holland will be found an account of whatever is most remarkable in the present condition of the Dutch provinces: it now remains to give a similar account of those denominated Belgic,—with a slight sketch of the history of both divisions.

Belgium, extending from 49° 30′ to 51° 40′ of north latitude, and from 2° 30′ to 6° 58′ of east longitude, is bounded on the south and west by France; on the north by Holland and the German Ocean; on the east by the Prussian duchy of the Lower Rhine. From Ostend on the north-west, to the extreme point of Luxemburg on the south-east, is about 180 British miles, the greatest length of Belgium; and a line drawn at right angles to this, through South Brabant and Hainaut, would measure 120 miles, which may be regarded as the medium breadth; the superficial extent being estimated at 13,400 square miles, and the inhabitants at 5,226,000 souls,—on an average, 240 to the square mile.

The general appearance presented by this tract of country is sufficiently unvaried. Except some diminutive hills in the counties of Namur and Luxemburg, nothing occurs to break the level uniformity of its surface: no lake of any extent, no river of any majesty, no scene of nature, to arrest the traveller of taste. Some forests in Flanders, indeed,—that of Soignies in Brabant, and the venerable one of Ardennes, still extending almost from Valenciennes to Treves on the south-east, give an air of picturesqueness to some of those districts; yet Belgium, in comparison with other regions of Europe, has little to diversify its aspect, and less to adorn it. It is not, however, destitute of a certain grace, which, if not strictly beautiful, is still calculated to yield pleasure to the observer. Ascending the church-tower of any of its towns—the only position from which an extensive view can be commanded,—the eye ranges over a vast space of fertile and highly cultivated land, intersected with numerous canals, and studded with towns and villages in every direction, the smoke and the spires of which give a character of diligence and life to the prospect; while the multitudes of antique monastic buildings, generally embosomed among woods, or here and there a feudal castle, with its high peaked roofs, its quaint architecture and obsolete defences, reflect back upon the mind a touching shadow of the romantic ages. Nor is the scene without interest, borrowed from times of a more recent date. For the last three hundred years, Belgium has been the great arena of the political contests of Europe: from the age of William of Orange to that of Buonaparte, the destinies of the world have been fought for and decided here; and no country contains as many spots rendered famous by the memory of sieges, and treaties, and victories.

A transient visitor longs for the sublime in natural scenery; the useful is more valuable to a resident: and if Belgium ranks low in the estimation of the former, it should rank proportionably high in the estimation of the latter. No part of the Continent is better adapted for the purposes of life, or yields a more ready and abundant reward to the labours of the husbandman. For six centuries it has vied with Lombardy, for a shorter period with England, in meriting to be entitled the garden of Europe; a distinction which it owes no less to the fertility and conveniences of its soil, than to the experience and activity of those who till it. A rich sandy loam, with but a few inferior patches of clay,—dressed with neatness, and copiously manured, without the use of fallows, gives a constant return of twelve or ten to one in the best districts, and of seven or six to one even in the worst. The artificial products of its agriculture differ not materially from those of our own country: its corn, fruit, hemp, flax, have long been known; its wool, though not equal to that of England, is of good quality, having been improved by the mixture of a breed imported by the Dutch from India; and its horses and cattle are greatly esteemed for their strength and size. In regard to native vegetables, the same similarity is to be observed; the relative quantity alone being sometimes different from what is found with us, very rarely the kind. The hop-plant once formed an exception: it was introduced by Henry VIII., from Belgium, where it grows spontaneously. In Luxemburg, also, a little wine is produced; though otherwise that province is the most barren of the whole.

This similarity in the vegetable productions of England and Belgium might lead us to expect a corresponding similarity in their climates: and observation confirms this supposition. The climate of Belgium closely resembles that of the south of England: the air, though cold, is healthy; frequent sea-breezes keep it in a state of purity; and as the soil, owing to its sandy nature, is far drier than that of Holland, as it is also far more elevated with regard to the level of the waters,—the mists and tempests, the wet and cloudy winters of the northern provinces, are much less common here.

The comparison which Belgium may sustain with England, in regard to its climate, and the productions of its soil, will fail, if extended to the interior of its rocks. Belgium has few minerals; and those few not valuable or extensively distributed. Some copper and lead at Namur, some iron in Luxemburg and Hainaut, some calamine and zinc near Limburg, one or two coal-mines in the tract between Maestricht and Charleroi are all it has to boast of in this respect; and the scantiness of nature has been slightly compensated by the diligence or skill of the inhabitants. Their mines have never been judiciously managed; their coal-mines, in particular, till the late war, by excluding all regular intercourse with Britain, forced the people to depend on their own resources, were almost entirely neglected: they are now increasing in importance and productiveness, though still far within the limits of their capability.

The levelness of surface, which is unfavourable to the discovery and working of mines, is highly advantageous, in another respect, by the facility it affords for constructing canals. In Belgium, as in Holland, canals perform the services which roads perform elsewhere: they intersect the country in every direction, and form the usual mode of communication from one town to another. Some of them are as old as the tenth century; they abound in all quarters at present; and the existing government, avoiding the niggardly policy of its predecessor, is anxious to keep them in repair. The rivers of Belgium are not unlike canals in their appearance, and equally useful to commerce. None of them are of great length; but the slowness of their descent accumulates their waters, and allows them to be navigated far above their mouth. The Maese, or Meuse, is the most interesting in its scenery. It rises in France, from the elevation that gives birth also to the Aube, the Marne, and the Saone; and after receiving the Sambre at Namur on its left side, and the Atwaller on the right at Liege, it joins the Waal by several outlets in Northern, or Dutch Brabant. Between the towns just mentioned, its shores exhibit, on a smaller scale, much of the romantic scenery which adorns those of the Rhine. The Scheldt, as far inferior in beauty to the Maese, as it is superior in utility for trade, rises also in France, near Bohain in the Aisne Department; is augmented by the Lys on its left side at Ghent, by the Dender and Rupel on its right; and discharges itself by two large channels, the eastern Scheldt, which passes by Bergen-op-Zoom, and the western Scheldt, which passes towards Flushing, as well as by a multiplicity of smaller ones, the interlacements of which give rise to the islands of Zealand. The Scheldt is not so long as the Thames, but like that stream it deepens and widens to a great extent by the resistance of the sea.

By means of those rivers, their subsidiary streams, and the canals which connect them with each other and with the Rhine, Belgium has an expeditious and safe communication with all places in the north of France, with the west of Germany, and even with Switzerland. Such advantages for commercial intercourse were soon laid hold of by the inhabitants. The fertility of their soil, their fortunate position in regard to neighbouring nations, combined with those advantages to introduce an extensive and flourishing trade during the early ages. The wealth which this generated and diffused over the towns of Belgium, secured their political freedom at a period when, excepting Italy, nothing like freedom, or even well organized despotism, existed in the world: and this new stimulus re-acted powerfully on the cause which had produced it. The first enterprises of the Belgians were directed to the neighbouring coasts of Britain and Denmark. The wool brought back from the former employed thousands of workmen in Bruges, Ghent, and Antwerp: and before the middle of the twelfth centory, Flemish cloths were widely sold over France and Germany. Already, in the preceding century, the ships of Friesland were to be found in the Belt; some of them even ventured to visit the Levant. Without a compass, these enterprising mariners had the courage and skill to approach the Pole, and coast round the northern capes of Russia. From the towns of the Baltic, Belgium acquired a portion of the Oriental trade, the course of which was at that time by the Black Sea through Russia to those regions. In the thirteenth century, it is true, this trade began to fail; the crusades had opened a new path for the commodities of India by the Mediterranean; the states of Italy seized upon the lucrative employment of transporting them; and the Hanseatic League was formed in Germany. But those changes, while they altered the direction of the Flemish trade, greatly increased its quantity. Belgium soon became the emporium of Europe, the point of communication between the north and the south. Seamen had not yet universally adopted the use of the magnet; and even such as had, were accustomed, according to their former practice, to creep slowly along the coasts, doubling every promontory, and scarcely on any account venturing into the open sea. The time consumed in such voyages may easily be conceived. But the harbours of the Baltic are often frozen during winter, and inaccessible to any ship. Vessels, therefore, which could not easily traverse the wide distance from the Mediterranean to the Belt, in a single season, were glad to find a place of union midway between both. Belgium, with an immense extent of country behind it, and connected with it by canals and navigable streams, open also by safe harbours to the ocean on the west, seemed expressly suited for such a purpose. It was not slow to profit by its circumstances. Staples were erected in all the principal towns. Portuguese, Spaniards, Italians, French, English, Germans, Danes, Swedes, travelled thither with merchandize from all quarters of the globe. The competition of sellers lowered the price; domestic industry was quickened by the existence of a near and abundant market; and the Princes of the country, awakening at length to their true interests, encouraged the merchant by important privileges, and protected his foreign speculations by special treaties with external powers. United among themselves, the Flemish towns at last ventured to renounce the Hanseatic Confederation, and even to defy that powerful enemy wherever it opposed them. The Hanse merchants, when the harbours of Spain were shut against them, felt constrained reluctantly at length to visit the markets of their rivals, and purchase Spanish goods in the staples of Belgium.

During the fourteenth and fifteenth centuries, Bruges in Flanders was the heart of commercial Europe; the great fair of all nations. In the year 1468, a hundred and fifty merchant ships might be seen at once all entering its harbour of Sluys. Besides the rich magazine of the Hanse Confederation, the warehouses of fifteen mercantile bodies were to be found here; with factories and families of merchants from every country of the civilized world. It was the emporium of all northern products for the south; of all southern and oriental products for the north. The latter proceeded in Hanse bottoms through the Sound, and along the Rhine to Upper Germany, or were carried by land eastward to Brunswick and Luneburg.

The prosperity of Bruges, Ghent, and the neighbouring towns, was accompanied with unbridled luxury, and with a turbulent spirit of insubordination, which, at last, brought on their downfal. They quarrelled with their rulers; and the issue was unfortunate. Maximilian of Austria, whom the people of Bruges had even the boldness to lay hold of (1497,) and confine with his suite till their grievances were redressed, was obliged for a time to give way; but Frederick III. Maximilian's father, used every effort to revenge this insult. He seized the harbour of Sluys; and thereby during ten years greatly impeded their trade. The Flemish weavers, too, who had now settled in England, began to produce cloths of their own; the Italian merchants began to frequent other fairs; the Hanse Confederation, exasperated by the haughtiness of the city, carried away their factories; and the commerce of Bruges gradually sunk,—but slowly, as it had arisen slowly.

The decline of Bruges produced a change, but no diminution in the general trade of Belgium. Antwerp now stood forth to fill up its place; and each source of wealth, as it ceased to flow in the channels of Bruges, was sedulously diverted into those of its rival. If the Italian merchants, the Hanse Confederation, the cloth-dealers of England, turned away from the port of Sluys, it was only to enter that of the Scheldt: and Antwerp, under the government of Charles V. had become the liveliest and most splendid city in Christendom. Its excellent haven invited ships; its privileged fairs allured traders from all quarters. The industry of Belgium had mounted to its summit at the commencement of the sixteenth century. The produce of grain and flax, the rearing of cattle, the curing of fish, enriched the peasant; arts, manufactures, and commerce, the townsman. Ere long the productions of Flemish industry were to be met with in Arabia, Persia, and India; Flemish ships covered the ocean; we find them even on the Black Sea contending with the Genoese: and their mariners were distinguished from all others, by hoisting sail at every season, even the rudest of the year.

When the new route by the Cape was discovered, and the Portuguese trade undermined that of the Levant, Belgium did not feel the blow which laid prostrate the Italian republics. Portugal erected its staples in Brabant; and the spices of Calicut were displayed in the markets of Antwerp. Hither also flowed the West-India produce, with which the proud indolence of Spain rewarded the diligence of the Low Countries. The East-India sales of Antwerp attracted the Fuggers and Welsers from Augsburg, and the richest companies of Florence, Lucca, and Genoa. The Hanseatic Confederation exposed their northern productions here; and our English company of merchant adventurers are said to have employed above 30,000 of its people. The renown of Antwerp extended itself over all the earth. Towards the conclusion of this century, a society of Turkish traders begged permission to settle there, and circulate from that centre the products of the east over Greece. With the exchange of goods, that of money also increased Flemish bills were current in all quarters of the globe. Antwerp, it is maintained, transacted more business at that period within a month, than Venice had done within two years, during the most brilliant epoch of its history.

In 1492, the Hanseatic Confederation held its general congress in Antwerp, not in Lubec, as formerly. In 1531, the Exchange was built, the most magnificent in Europe at the time, and afterwards the model of that of London. The city contained 200,000 inhabitants; but the floating multitude, the world which pressed towards it on every side, exceeds all belief. Above 500 ships entered and left its harbour daily; above 200 coaches daily passed through its gates; upwards of 2000 waggons arrived weekly from Germany, France, and Lorraine, not reckoning farm-wains and provision-carts, which commonly exceeded 10,000. The exports and imports seemed infinite in variety and immense in quantity. The spiceries and drugs alone, which Lisbon sent into it, were valued at a million of crowns in the year.

But the splendour of Antwerp was not destined to be lasting. It departed like that of Bruges; and not slowly, as that of Bruges had done; it was extinguished at once in the zenith of its glory, and has never more returned. The stern oppression of tyrannical governors, the sterner persecution of inquisitors, the devastations of a savage and fanatical soldiery, all that is cruelest in the scourge of war, when despotism and bigotry unite to make it cruel, descended upon Antwerp, like a thunderbolt, and destroyed it irrevocably. The peaceful merchant fled in terror from a Granvella and an Alva, and all the riches and power of Belgium fled along with him. Since the end of the sixteenth century, a succession of unfavourable circumstances,—the change of masters, the invasion of enemies, the preferable condition, and hence the successful rivalry of Holland or of England, have perpetuated the depression brought on by the blind and execrable policy of Philip II., and nothing can be stronger than the contrast of what Belgium *is* with what it *was*. For the last 200 years its external trade has been trifling, and up to the present date, it has not sensibly increased. Few of its vessels visit foreign countries, and the scanty remnant of its trade is mostly inland to Germany. The western districts, however, export some flax and hemp; the other districts, corn and various kinds of seed. The manufactures have experienced an enormous, though not a proportional decline also. Some remains of the woollen trade are still found at Bruges; manufactures of lace and linen at Brussels, Antwerp, Louvain, Ghent, and Mechlin; Antwerp is farther noticed for its silk, Ghent for its cotton, and Liege prepares hardware and leather.

The ancient opulence of Belgium is, however, still discernible in the multitude of its towns and villages. No portion of Europe excites the attention of a stranger so forcibly in this respect. Many of these places are fortified: except on the borders of the Maese, where the ground contains marble and stone, they are uniformly built of brick, with steep roofs, the ends of which are directed to the street; and their general appearance is, on the whole, quiet and agreeable. **Brussels**, the chief city of Brabant, indeed of Belgium, is alternately, with the Hague, the seat of the Parliament of the New Kingdom. It stands on the Senne, beside a fine canal, which has lately been repaired. The city is beautiful and well built; has a college, an academy, and a public library, which contains 120 000 volumes. The Hotel-de-Ville is a large gothic edifice, with a tower 364 feet high. The Palace of Lacken is in the neighbourhood. Brussels stands among meadows, which, being frequently inundated by the Senne in winter, render its situation disagreeable, though their growth, so much the more luxuriant in summer, increases its beauty and convenience. The population is estimated at 75,000. They manufacture lace, hats, gloves, cotton, silk, and woollen cloths; their fabric of camlet was long the first in Europe. **Antwerp**, situated on the Scheldt, though fallen, as we have seen, from its former magnificence, is still the second city of Belgium. Its streets are broad and regular, and many of its public buildings are beautiful. The citadel, built by the Duke of Alva, was the scene of some bold enterprises in the wars of Philip II. The Exchange has already been mentioned, and the Cathedral is admired as the finest piece of Gothic architecture existing in Europe. The harbour has lately undergone some improvement; it was greatly damaged by our armies in 1814. Antwerp manufactures most of the laces known by the name of Mechlins; it is noted for its thread; it trades in diamonds, and prepares some cloths and chemical products. The population is 63,000. **Ghent** or **Gand**, the capital of Flanders, is placed at the junction of the Scheldt with the Lys and the small rivers Moere and Lierre, by which means it is divided into no fewer than 26 islands, most of which are bordered with quays. Ghent, like Antwerp, is greatly decayed. From one gate to the other is a distance of a league, but much of the intervening space is laid out in gardens, or even ploughed fields, and the city does not now contain above 57,000 inhabitants. It is remarkable as the birth-place of Charles V., whose punning boast, that he could put all Paris in his *Gand* (glove), has often been recorded. The principal manufactures are cotton-cloth and lace. **Liege** is the capital of the province which bears its name. It has an academy and a lyceum, but its churches and public buildings have suffered greatly during the late wars. The population is 50,000. As we have stated above, they work in various metallic fabrics, and prepare leather. **Bruges** is now reduced from its ancient grandeur to a population of 33,000. It stands on a beautiful plain, and its 260 streets are spacious and elegant, though consisting of old and thinly inhabited houses. Among its principal deficiencies is the want of springs or running streams; the water used in culinary operations has to be transported from the Lys and Scheldt by the canals. Of its public buildings, the steeple at the end of the great market-place is reckoned one of the finest in Europe; the ascent to it is by 133 steps. Bruges manufactures some woollen cloth, with a little cotton and lace. Of the other towns in Belgium, Mons, the capital of Hainaut, is the only one whose population reaches 30,000. Ostend and Sluys are the sea-ports; their extent is not remarkable. The former has 11,000 inhabitants; the latter, a somewhat greater number.

The *government* of Belgium, its establisments for *religion* and for *education*, are now merged with the corresponding peculiarities of Holland, and belong to the characteristics of that new kingdom, into which both countries have lately been combined. Before proceeding to discuss those topics, therefore, it will be proper to cast our eye over the *history* of the provinces which are now united. The circumstances under which that union has taken place, will then naturally fall to be described, and must of course comprehend the *government*, with its revenue and forces, the *religion*, and the state of *education*, which are now alike for all.

History.—The early history of the Netherlands has nothing in it very interesting or peculiar. Like that of most European states, it commences with an account of their subjugation. The Romans had penetrated into those countries, and conquered them all before the beginning of the Christian era. The people had not yielded tamely. The Belgæ, inhabiting the left bank of the Rhine, are described by Cæsar as the only Gallic tribe brave enough to withstand the irruptions of the Teutones and Cimbri; the Frisians, occupying the right bank of the same river, made a stubborn opposition in the middle of their swamps; and the Batavians, who dwelt upon the islands of Zealand, were honoured as the boldest of all the neighbouring clans. Their opposition was vain, however; and their gallant attempt to cast off the yoke in Vespasian's time was equally vain. They submitted to the Romans, and participated in the improvements which that people usually communicated to the nations it conquered. The canal of Drusus, from the Rhine to the Flevo or Zuyder Zee, still exists, though its character is altered; and the first dykes, which protected Holland from the ocean, are ascribed to the enterprising industry of those governors. The stout spirit of resistance shown by the Batavians had procured them respect in the eyes of their conquerors. The tribute of the province was paid in soldiers: Batavians formed the body-guard of the Emperor, as Swiss have done in later times; and the valour which had been displayed on the banks of the Rhine was equally conspicuous in other quarters of the empire. Agricola was accompanied and powerfully aided by them in his progress through our island; and the Dacian hosts recoiled when Batavians, in full armour, swam across the Danube to attack them.

During four centuries we find Batavians enumerated among the Roman armies; but after the time of Honorius, their name vanishes from history. The eruption of the northern nations swept over their country in its course, and destroyed all the monuments of Roman power and ingenuity. The monarchy of the Franks, which arose on the ruins of Gaul, had, in the sixth and seventh centuries, embraced all the provinces of the Netherlands, and planted the Christian faith in them. After an obstinate struggle, Charles Martel overcame Friesland the last of all; and Charlemagne united the whole of those countries with the wide empire, which he had formed for himself out of Germany, France, and Lombardy. When Charlemagne's possessions were again divided among his successors, the Netherlands became at one time provinces of Germany, at another of France; and we find them at last designated by the names of Friesland and Lower Lorraine.

With the Franks arrived also the constitution of the north; and here, as elsewhere, it gradually degenerated. The stronger vassals separated in process of time from the crown; and the royal officers laid hold of the districts over which they were sent to preside, and rendered them hereditary in their families. But those revolted vassals could not hope to resist their king, except by the help of their inferior retainers; and the support thus required was repaid by fresh infeudations. The priesthood, in the mean time, also, growing wealthy and powerful, had extorted for itself an independent existence in its abbeys and episcopal sees. And thus, in the tenth, eleventh, twelfth, and thirteenth centuries, the Netherlands were split down into a number of petty sovereignties, the heads of which held partly of the empire, partly of France. By purchase, marriage, inheritance, or conquest, several of these lordships were frequently united under one master; and in the fifteenth century we find the house of Burgundy in possession of almost the whole. Philip the Good, by prosecuting various claims, just and the contrary, had at last succeeded in uniting eleven of the provinces under his authority; and Charles the Bold, his son, increased them by the conquest of other two. And thus a new state had silently arisen in Europe, to which nothing but the name was wanting to make it the most flourishing kingdom in that quarter of the world. Such extensive possessions made the duke of Burgundy a suspicious neighbour to the king of France; and inspired the restless spirit of Charles the Bold with the plan of a conquest, destined to include the whole tract of country extending between Alsace and the mouths of the Rhine. The duke's inexhaustible resources justified, in some measure, this proud chimera: a powerful army threatened to realize it; and Switzerland already trembled for its freedom. But fortune forsook Charles at the battles of Granson, of Morat, of Nancy: he fell by an unknown hand; and his very corpse was all but lost among the carnage of his followers.

The future husband of his sole daughter and heiress, Maria, would now become the richest prince of the time. Maximilian, duke, afterwards emperor of Austria, and Louis XI of France, were rivals for this honour, and excluded the claims of humbler competitors. The States of the Netherlands dreaded the power and the tyranny of Louis: Maximilian was weaker and more distant; they decided for him. Their political foresight corresponded ill with the event. Philip the Fair, Maximilian's and Maria's son, acquired with his Spanish bride, the extensive monarchy which Ferdinand and Isabella had lately founded; Charles V. the next heir, augmented this inheritance by his grandfather's imperial crown; and the Netherlands, thus become the province of an overwhelming empire, had soon cause to experience and repent the change in their situation. During the succeeding age, this connexion with Spain gave rise to the most terrible, as well as the most glorious event of their history.

Prior to the Burgundian dynasty, and under it, the Netherlands, profiting by their natural advantages for commerce, had acquired considerable wealth; their wealth secured to them a free though complicated constitution; and they gradually rose to be the first trading nation in the world. The fulness of prosperity, which we have described as existing at Bruges and Antwerp, was but the concentrated result of an adventurous industry, abundant riches, and a generous spirit of independence, disseminated over all the country. At the accession of Charles V. the Netherlands abounded in resources beyond any other portion of his great dominions. The complex politics of this prince, his far-extended undertakings, gave him ample use for all their contributions; and his irresistible power allowed him to make various inroads on their freedom. The taxes he levied on them were immense, and granted unwillingly. He more than once introduced foreign troops into their towns, foreign officers into their government; the tribunals of the country were subjected to the revision of a supreme court established by the emperor at Brussels, and entirely devoted to his will. A still more glaring instance of his arbitrary procedure was the conduct he pursued with regard to religion. The new light of the Reformation, which in his reign was dazzling or illuminating every corner of Europe, had early found its way into the Netherlands, and excited instant notice there. Foreign merchants, assuming the liberty of speech and action natural to persons in their situation, had already professed the doctrines of Luther. The Swiss and German soldiers of Charles were often Protestants: the nobles of the country were accustomed to study in the academies of Geneva: refugees from France and England were allured by the freedom of the Low Countries to escape from the pressure of domestic persecution; their mechanical skill or commercial capital was welcomed as a benefit; and their opinions were listened to with toleration or approval, by a people in whom an intercourse with remote and dissimilar nations had softened the asperities of bigotry,—in whom the long possession of wealth and social comforts had developed a spirit of inquiry and comparison, while their trading prejudices, their exclusive respect for diligence, and their love of gain, were shocked at the expensive, *unproductive* establishment—the lazy monks and haughty prelates—of a hierarchy, whose gorgeous splendours suggested no idea but that of useless cost to their calculating and unimaginative minds. The art of printing circulated those speculations among the higher classes. Bands of adventurers, animated by the love of truth or the love of change, moved over the country from place to place, to circulate them among the lower. To the serious, those *speakers*, as they were named, could preach with all the fervid zeal of missionaries and apostates: for the careless and light of heart, they had songs, and farces, and buffooneries in every possible style of contrivance. Such multifarious causes did not work in vain. The Romish church in the Netherlands, attacked at once by argument and ridicule, by enthusiasm and self-interest, was nodding to its fall before the danger had been met or even noticed. Its guardians at length awoke, and the usual expedients were put in motion. Charles V. had agreed to tolerate the Evangelical creed in Germany, because its professors were formidable in their united strength; but he seemed anxious to make amends for this compelled forbearance, by a double severity in treating the heretics of the Netherlands. Contrary to the fundamental laws of the state—contrary to the universal wish, no less than to the voice of justice and humanity, he introduced religious tribunals into the country, to superintend the execution of his *edicts*, in which the most stern and relentless vengeance had been denounced against any variation, however slight, from the Romish creed. The guilt of having advanced heretical doctrines, of having even assisted at a secret meeting of the Reformed, was punished with death—by the axe, if the culprit was a man; women were buried alive. A relapsed heretic was committed to the flames, and no recantation availed him. The ministers of Charles were diligent enough in their obedience. Fifty thousand persons perished on the scaffold here, "suffering for conscience sake," during his reign. No privacy, however sacred, was secure; no age, or sex, or rank, was spared; and this once cheerful land was overshadowed with grief, and terror, and silence. Posterity have learned, with a kind of satisfaction, that, in his old age and retirement, Charles himself began to doubt; that the spirit which had never felt for the fate of another, was doomed in its feebleness to experience the blackest terrors for its own fate, and to leave the world it had wasted and deformed, under *a weight of blood* which superstition itself could no longer alleviate.

Charles, however, was less a bigot than a despot: he relaxed his cruelties when he found they would interfere with the prosperity of a country whose revenues he needed so much; and he preferred allowing the continuance of erroneous doctrines at Antwerp, to the hazard of destroying the commerce of the city in extirpating them by an Inquisition similar to that of Spain. The people, too, were inclined to suffer much at his hands. He was their countryman; spoke their language, adopted their manners, and visited them often. The fame of his victories, his talents, and his power, laid hold of their admiration; and the promotions which he lavished on their chief men, secured him a permanent interest among the inferior. And if all those persuasives could not *lead* to obedience, the extent of his other dominions was sufficient to *force* it. The prompt and hard punishment to which he had condemned the mutinous inhabitants of Ghent, was a lesson of humility and submission to all.

But in the case of Philip II. his son, every thing was different. With a heart as stony as his father's, Philip united an intellect vastly inferior by nature; and the gloomy tutelage of monks had narrowed and obscured it still farther. He was born in Spain; and the harsh sadness of his temper was best fitted to relish the solemn and monotonous style of society prevalent there. In his youth he had been sent to visit the Netherlands, that his presence might conciliate the affections of the people; but his haughty deportment, his unaccommodating character, produced quite an opposite effect. Philip loved not the Netherlands; and the feeling was mutual. At the abdication of his father (1556,) the States evinced their distrust of Philip's intentions by the vain attempt which they made to guard against them. The splendour of a spectacle so extraordinary could not lull their vigilance; and an additional oath was imposed on Philip, forbidding every shadow of innovation in the established laws of the country.

The suspicions which arose so early were soon abundantly confirmed. By the treaty of Chateau-Cambresis, Philip was delivered from all foreign enemies; yet he obtinately continued, under the shallowest pretences, to retain a body of Spanish troops, occupying the garrisons and consuming the resources of the country. The edicts of his father were brought forward anew, and the more strict and impressive execution of them was intrusted to Cardinal Granvella, a man whose inflexible disposition and consummate political skill were well fitted for the purposes of Philip; but whose proud contemptuous behaviour disgusted the nobles, while his rigid severity exasperated the people. Under the advice or superintendence of this man, Philip appointed Margaret of Parma, a natural daughter of Charles V. to be regent of the Netherlands, and returned to Spain, where complaints and representations were not slow to follow him. The foreign troops had remained till long after the promised period; the spiritual tribunals were active; and the cardinal, who had never been popular, was fast acquiring universal execration. The appointment of fourteen new bishoprics, showed Philip's zeal to exterminate heretical doctrine, but was highly disagreeable to every class of the community. It dissatisfied the nobles, because it abridged their political importance by the addition of so many votes entirely at the royal disposal in their deliberative assemblies; the existing clergy, because it divided and extenuated their revenue; the people, because it was meant to cramp their freedom. The national discontent had begun to exhibit itself in actual commotions, before Philip, having vainly tried every subterfuge, could be prevailed on to recal his minister (1564,) and give promises to remit the execution of his father's edicts, and redress the many grievances of the state. Nor was the calm, which these occurrences diffused, of long continuance. Philip intended nothing so little as allowing the growth of heresy, and he saw no method but that of persecution for preventing it. In place, therefore, of removing the inquisitorial court, which differed only in name from the Spanish Inquisition, and which all men, Catholics as well as Reformed, agreed in abhorring, he transmitted express orders to his representative, the Duchess of Parma, to quicken the movements of that tribunal, and protect its decrees with all the force of the civil power. The Inquisition needed no such stimulus. It had already done its work effectually enough to frighten 100,000 families from their native country; and now, when no hope appeared of deliverance from it, the people rose in many towns of Flanders (1566,) forced the prisons of the Inquisition, and set free all who were confined there on religious accusations; delivering themselves up, at the same time, as might have been expected, to many other measures of a less excusable nature. This uproar would have been appeased, or would soon have sunk away of itself; but in the meanwhile most of the nobles, participating in the discontents of the populace, to which peculiar discontents were added in their own case, seconded, though they affected not to countenance, the popular proceedings; and formed themselves into a combination, which has become known to history by the epithet *Gueux* (beggars,) applied to the members of it in contempt, by a minion of the court, when they appeared in Brussels to lay their petition and remonstrance before the regent. The name *Gueux* was adopted with an indignant smile, by the confederacy itself; and the symbols of beggary, the wallet and staff in miniature, became the rallying emblems of the dissatisfied, and were to be seen on the persons of men and women over all the country.

Alarmed by these unequivocal symptoms of general revolt, Philip dispatched the Duke of Alva from Spain, at the head of 10,000 men, to enforce obedience, and avenge the opposition already shown to his mandates. The Duchess of Parma was glad to retire from the storm, which, in contrasting Alva's character with the circumstances of the state, she saw clearly to be approaching; and Alva was appointed governor in her stead. His entrance upon office was the signal for universal despair. Bigotted in his creed, immoveable in his determinations, savage in his temper, he hated the Flemings for the favour shown them in the former reign; and the country soon groaned under the weight of his resentment. With his council of twelve, nominated by himself, and entirely at his discretion, he proceeded strongly in the work of destruction; and the scaffolds soon reeked with the blood of thousands, guilty or innocent, as they happened to incur his displeasure. The people were driven to madness; they wanted but a leader to rise in open rebellion, and brave the very utmost of their tyrant's fury. A leader was soon presented to them; and one fitted for the crisis beyond any other person of his time.

William, Prince of Orange, was the representative of the noble family of Nassau, which had once given an emperor to Germany, and for many ages had occupied an honourable rank among the chiefs of that country. Early taken under the protection of Charles V., he had lived constantly at court, enjoying the intimate familiarity of that monarch, and participating in all his secrets. William's circumspect demeanour procured him the surname of *silent*; but under this cold exterior, he concealed a busy, far-sighted intellect, and a generous, upright, daring heart. He had extensive possessions in the Netherlands; and had been employed there by Charles in various important duties, in the discharge of which, his talents, his integrity, his manners, had procured him universal confidence and respect. Disappointed in his expectation of the regency under Philip, who hated and feared him, he had continued to act with the same calm stedfastness, equally resisting the arbitrary measures of government, and repressing the rash attempts of the harassed people. On Alva's approach he retired to Germany; and the fate of Count Egmont, who shared the national favour with him, and had perished on the scaffold at Antwerp for no other crime but sharing it, soon showed how prudent this step had been. The tribunal which had condemned his friend, now summoned William to appear likewise; and as he naturally refused to comply, they proceeded to confiscate his property, and brand him as a traitor. William was not of a humour to brook such treatment tamely: and patriotism combined with ambition to strengthen his purpose of finding redress. Having formed an alliance with several princes of Germany, and collected a body of troops, which multitudes of Flemish exiles were rapidly augmenting, he formally renounced his allegiance to the governor, and entered Friesland at the head of an army (1569.)

His beginning was unsuccessful. Alva hastened to meet him; the raw soldier could not stand against the veteran; William retired into Germany once more; and the Spaniard returned in triumph to Brussels. But his triumph was not long undisturbed. He had erected a statue of himself in the citadel of Antwerp; he had represented it as treading under foot two smaller statues emblematic of the States of the Netherlands; and was proceeding quickly to demonstrate the correctness of this allegorical device, by levying the most oppressive taxes, of his own authority, and massacring, with every circumstance of ignominy and savageness, all such as refused to comply with his requisitions,—when his bloody career was interrupted by intelligence that the town of Brille was taken, and the whole island ready to revolt. He hastened thither to quell the tumult, and crush the *Gueux* patriots, or pirates as he called them, who had caused it. But the infamy of his conduct preceded him; William of Orange, under whose instructions the conquerors of Brille had acted, was advancing from the east with a fresh army; and the entire provinces of Zealand and Holland simultaneously threw off the Spanish yoke. Alva made vast efforts; but they were fruitless. He took Naerden and Haarlem, and butchered their inhabitants; but he failed before Alcmaar; a fleet which he put to sea with great exertion was defeated and destroyed by the Zealanders; and on Philip's order he returned to Spain, to boast that in five years he had delivered 18,000 heretics into the hands of the executioner, and to meet the reward which such a servant of such a prince unfortunately does not always meet—the suspicion and hatred of a master for whom he had sacrificed honour and humanity, and condemned himself to permanent and universal detestation.

Requesens succeeded Alva. He was a milder and a better man; but the time for mildness was gone by. Some years before, a governor like Requesens might have retained the Netherlands under Philip; but the horrors of Alva's regency, the massacre of St. Bartholomew in France, had put to flight "respective lenity," and "fire-eyed fury" was their conduct now. It is dangerous to drive even the feeblest of creatures to despair; and Philip found he had calculated too far on the phlegmatic patience of his northern subjects. The dull perseverance of their ordinary character was now changed into a grim and adamantine fixedness of purpose to suffer all, to dare all, but never to submit. "Talk not of surrender," replied they to Valdez, the general of Requesens, at the siege of Leyden, when famine was already carrying them in hundreds to the grave: "Our provisions are not exhausted, and if they were, if all else should fail, we would eat our left arms and fight with our right, that we might die fighting against our tyrants." Their firmness, on this occasion, was rewarded. The sluices were opened, the country was laid under water; a strong south-west wind rendered fruitless every attempt to drain it; and the Spaniard made a frightful retreat, leaving the flower of his army buried in the marshes, or hewn to pieces by the Flushing boatmen, who hung upon his skirts, with fury and revenge in their hearts—their harsh countenances rendered harsher by scars sustained from the same enemy in former broils, and their caps surmounted each by a crescent, having the inscription, *Turks before Papists.*

This ineffectual siege of Leyden is the most remarkable transaction of Requesens in the Low Countries. It was followed (1575) by some abortive attempts at negociation, the Emperor Rodolph, and our Queen Elizabeth, acting as mediators. Neither party was in a mood for negociating; and Philip instructed Requesens to prosecute the war with fresh vigour. The latter endeavoured to comply; he was beaten back at Woerden; but he reduced Ziriczee, had entered Zealand, and was meditating an attack on Holland, when death overtook him suddenly, and the Netherlands were left without a governor.

The death of Requesens, at this juncture, was a keen blow to the Spanish interests. The troops had received no pay for many months; the absence of a general made them clamorous in their demand; and as no funds existed to satisfy it, they renounced the controul of their officers, spread over the country in search of plunder, sacked the city of Antwerp with the most horrible outrages, and seized upon the fortress of Alost, from which they threatened other towns with a similar violence. The southern provinces had hitherto participated rather in the feelings than the actions of their revolted countrymen; and the seat of war had been chiefly in Holland and Zealand. But this fearful visitation roused even the most timorous: In 1576 all the states united themselves by a treaty, named the Pacification of Ghent, having for its object to expel the foreign soldiery, and restore the ancient liberties of the country; and Don John, the new governor, found all the Netherlands, except Luxemburg, shut against his approach. Don John's ambitious views induced him to temporise: he affected to sanction the Pacification of Ghent; was received peacefully into his government; and the country had liberty to breathe for a moment. It was but for a moment. Don John watched his opportunity to seize the castle of Namur: he recalled the Spanish troops, and the fire of war was kindled again. His opponents were little able to resist, and their strength was still farther weakened by intestine division. The Prince of Orange's guarded and patriotic behaviour could not appease the jealousy of the Catholic confederates, or quench the envy of his ancient rival, the Duke of Arshot, who affected to lead them, as William did the Protestant party. While the latter, therefore, made application to Queen Elizabeth for assistance, the other privately invited the Archduke Matthias, brother, and afterwards successor of the emperor Rodolph II. to come and take upon himself the office of governor. The Prince of Orange was too quick-sighted, and too public-spirited to let slip so fair an opportunity of at once acquiring strength by foreign connexions, and sowing discord between the German and Spanish members of the Austrian family. He accordingly welcomed Matthias on his unexpected arrival at Antwerp, and persuaded the States to set him at their head. The Prince himself was appointed his lieutenant; and Arshot's plan was doubly unsuccessful. But neither did William's turn out according to his hope. Matthias received no support from Germany, and soon fell into contempt; while Don John, reinforced by the celebrated Alessandro Farnese, Prince of Parma, with 18,000 veterans, had beaten the army of the States at Gemblours, and was making rapid progress in the subjugation of the provinces. Don John died soon after, —of poison, by Philip, it was suspected, or of chagrin at the failure of his schemes on the English crown, which he had dreamed of obtaining with the hand of Mary Queen of Scots; but his death brought no relief to the confederacy. Matthias returned without honour to Prague; the Duke of Anjou, who was next called in, could be of little service; and, while Parma was advancing in his conquests, the Duke of Arshot was smoothing the way for him, by fostering divisions and cabals among the provinces to be attacked.

To obviate the evils of dissension, William assembled the Northern or Protestant States, among whom his influence was the most extensive, and who hitherto had stood the brunt of the war alone. He was fortunate enough at last, to combine them into a permanent whole. On the 23d of January, 1579, was signed the famous UNION OF UTRECHT, at the city whose name it bears, by deputies from the provinces of Holland, Zealand, Utrecht, Friesland. Groningen, Overyssel, and Gelderland. It was the fundamental article of the Dutch Republic, destined after to become so conspicuous an agent in the political transactions of Europe. The main stipulations, for the present, were, that the Seven Provinces should join themselves in interest as one, each individual still retaining its own private customs; that in disputes between two, the rest should interfere only as mediators, and that all should assist each with life and fortune against every foreign enemy. Separately, the provinces were weak; and though united as firmly as the bundle of arrows, the badge and emblem of their alliance, it might still seem doubtful if this new republic would survive its infancy. Its members had not faltered in the contest, but they doubted of the issue themselves. Their first coin was stamped with the image of a ship struggling amid the waves without oars or sails; and the motto was, *Incertum quo fata ferant.*

It was indeed a perilous enterprise in which they were engaged. A small community of fishers and herdsmen, hitherto unknown among nations, had come down into the lists against a monarch, before whom the most powerful kingdoms of the world had lately trembled for their liberties. With no resources but their own activity, no tactics but their own despair, the Dutch had ventured to defy the commander of the veterans of Charles V. and the possessor of the American mines. The contest at first view might appear hopeless, and preferable to submission, only, as dying nobly on the field of battle is preferable to dying unjustly on the scaffold. A closer inspection, however, showed the prospect in less gloomy colours. The Hollanders were poor; but the enemy's wealth lay widely scattered, and bold adventure might snatch a part of it. The Flemish exiles, driven from the peaceful occupations of the land, had betaken themselves in great numbers to another element; and the rich fleets of Spain were often captured by them. By degrees, too, the trade which was thus obstructed, sought out other channels; and Holland, the asylum of the persecuted from every nation (who were naturally the most inquisitive and enterprising of each nation), soon abounded in persons fitted for all kinds of commerce, and ready to grasp at every branch of it within their reach. As their maritime speculations prospered, greater numbers, and more capital, became engaged in them: they at length acquired a navy, which could venture to the Indies, and strike at the root of their oppressor's prosperity Philip had impoverished and ruined that part of the Netherlands which still adhered to him; the Indian trade of his Portuguese subjects was snatched away before it could reward the labour of conquering Portugal, and keeping it conquered; and Spain, at no time distinguished for commerce, had already begun to sink into that state of languor from which it has never since awoke. The gold of Potosi, in spite of all his efforts, found its way to the markets of Amsterdam: his own subjects did not manufacture; and the very equipment of his armies gave vigour and riches to the people they were sent to subdue. His forces seemed numerous, but his plans were still more so. The jealousy entertained against his father continued to subsist, though the power which had given rise to it was fast ceasing. A kind of Catholic knight errantry made Philip take part in every religious quarrel which agitated Europe during that period: his armies and his treasures were repeatedly called from their most necessary functions, to lend assistance to the partizans of the League in France. Ambition made him seize the crown of Portugal; ambition combined with resentment and fanaticism to make him grasp at that of England. And each new undertaking, each new acquirement, while it weakened his own strength, by extending it over a wider surface, procured for the Hollanders, openly or secretly, a new ally.

With William of Orange at its head, therefore, the new confederacy did not despair. Philip, who knew the Prince's importance, attempted to detach him by promises and gifts: when this was found to be impossible, he set a price upon his head. Superstitious fervour, so justified and rewarded, was likely in time to find some wicked maniac whom it could convert into an assassin. A first attempt failed; a second was successful. Balthazar Gerard murdered the Prince of Orange at Delft, (1584), being impelled, as he stated at first, by the Divinity; but allured also, as he afterwards confessed, by the less elevated hope of Philip's earthly recompence to do the deed. Philip's memory can suffer little by this imputation: the murderer of his own son could blacken his character no farther in the way of *murder.*

William's death was a heavy stroke to his fellow-citizens; but in proportion as it excited grief for the fate and for the loss of their leader, it rendered more implacable their hatred of his destroyer. Nor was their situation yet so low as Spain believed. The Duke of Anjou, their late governor, had left them, indeed, with feelings of irritation and disgust, which were repaid him with usury: but William's exertions had kept the Prince of Parma busied in the southern provinces, where much work still remained for him. By William's negociations, seconded by the suspicious measures of Philip, Elizabeth of England, though she rejected the sovereignty of the Netherlands repeatedly offered to her, had been induced to lend them secret assistance in troops and money; and she now openly espoused their quarrel. As security for payment, the States delivered up to her the towns of Bille and Flushing, with the castle of Rammekens; and she sent them an army, with the earl of Leicester to be their governor. Leicester dissatisfied the people, and was recalled: but the soldiers continued; and being joined under Lord Willoughby, with the forces of the republic, were placed at the disposal of Maurice, the late Prince's son, a young man whom the gratitude of his country had raised to the station of governor, and who soon showed talents that would have deserved it independently of gratitude.

His talents, however, were all required in this emergency; and but for other circumstances, they would hardly have suffered to meet it. Parma had already secured Ghent, Bruges, and lastly Antwerp, the hardest of his conquests, as well as the most serviceable. In the south, every thing must soon have been entirely at his disposal; and Holland might then have justly trembled before his accumulated force. But Philip's wars with England, his *Invincible* Armada, thinned the ranks of Parma, and dissipated the treasures which should have maintained him. In addition to this, that general was twice dispatched to France, to mingle in battles which had no bearing on his own success; and the Dutch, now strongly supported by Elizabeth, frequently undid in his absence what it had cost him infinite pains to effect before his departure. Between Maurice and Philip, the task of Parma was like Penelope's web; no skill or energy could avail him. Compelled to vibrate between France and Holland, he accomplished nothing permanent in either. During his second invasion of the former country, he had succeeded in thwarting the plans of Henry IV. both at Paris and Rouen. These were the last of his triumphs: he died at Arras next year (1592), and the Spanish cause in Holland died along with him.

Mansfeld, Ernest, Fuentes, his successors, impeded in their efforts by the French war, disobeyed by ill-appointed and mutinous troops, performed nothing of importance. The latter even lost Breda and Gertruydenburg to Prince Maurice. At length, in 1598, Philip closed his restless reign. The burden which had galled him near forty years, had long ago vanquished even *his* obstinacy; and Albert of Austria, husband of the Infanta Isabella, had, some time previously, been promised the sovereignty of the Netherlands, with merely a reversion in favour of Spain, should that princess die childless. Philip III. punctually obeyed the intentions of his father; but the states of Holland listened in silence to Albert's claim. At the head of a great army, he prepared to enforce it. Prince Maurice met him at Nieuport (1600;) and, with the aid of Sir Francis Vere, and the English auxiliaries led by him, gained a complete and splendid victory. Albert wasted his remaining forces in the trenches of Ostend: the town was gallantly maintained by Vere and his followers; and did not yield even to the talents of Spinola, till after it had stood a siege of three years, and cost him above 70,000 men. Under the same able general, Spain, to whom the reversion of the Netherlands was now become secure, Isabella having no children, made a last effort far beyond its diminished strength. But new efforts yielded no adequate result: Philip was weary of the contest; and, by the advice of Spinola, he agreed to treat of peace. After innumerable obstructions and delays on the part of the Dutch, who had now begun to reap profit from the war, and principally on the part of Maurice's faction, who hoped to make it serviceable to his ambition, a truce of twelve years was at last concluded, by the mediation of France and England, at the Hague, in 1609, Spain acknowledging the United Provinces as a free republic, and granting them every privilege which a free country has a right to demand. The revolt in Bohemia, which was already breaking out, the appearance of Gustavus Adolphus, and his victorious progress in Germany, soon gave full employment elsewhere to all the branches of the Hapsburg family. Combined with the vigorous administration of Richelieu, those events extinguished in Spain all desire of renewing its pretensions to Holland: no farther hostilities occurred, and a definitive treaty was signed in 1647, and ratified at the great peace of Westphalia next year, securing the rights of the United Provinces in the most ample manner, and finally stipulating the continuance of peace and free intercourse between two nations, whose strife had been so lengthened, so obstinate, and so bloody.

After the termination of this contest, which had established the freedom of seven provinces, and riveted the chains of ten, the history of the Netherlands presents nothing equally remarkable. What remains of it may be despatched more briefly. Belgium continued quietly subject to Spain, and lost all its commerce and enterprise: Holland went on rapidly increasing in both. Cornelius Houtmann had led the way to India in 1599; the Portuguese settlements, then subject to Spain, were in no condition to resist; and the Dutch by degrees acquired almost the whole of that lucrative trade. They planted colonies in the spice islands of the East; they gained settlements in America; their naval power continued to augment; they gradually became the factors and carriers of Europe. It is true, their government, at peace from without, was not equally at peace from within; theological disputes between Arminius and Gomar, to which political feelings soon became conjoined, had agitated the people violently in 1619, and tarnished the name of Prince Maurice by his share in the persecution of Grotius, and the death of the Pensionary Barnvelt. A more strict republican party also afterwards arose under the auspices of the De Witts, who had force and dexterity enough at the death of William II. (1650), to procure the abolition of the Stadtholdership. But those political fermentations slightly affected the industry and success of the great body of the nation. The public prosperity was stedfastly advancing; it had mounted so high in 1652, that the States did not hesitate to throw down the gauntlet to England, though her power was at that time wielded by the firm and steady hand of Cromwell.

Naval superiority was the subject of this contest; commercial and political jealousy embittered it. The Dutch had given refuge and countenance to many of the exiled royalists; their admirals refused to pay to the British the customary acknowledgment of superiority; Van Tromp, on the contrary, placed a broom at his mast-head, to signify that *he* would *sweep* the seas, and reign triumphant in them. But the cannon of Blake soon levelled this rude emblem, and the claim which it typified: De Ruyter and Van Tromp were beaten by him off Portland in 1653, after a furious contest of two days; and next year, Van Tromp was shot through the body, off the coast of Holland, while gallantly animating his men on the *third* morning of a battle, which his energy alone had proracted so long. Monk was the victor on this occasion. The Dutch were glad to make peace, and leave the dominion of the ocean in the hands where it was, and has ever since continued.

A severer trial awaited the Dutch republic shortly afterwards. In 1668, Louis XIV. profiting by the feebleness of Spain, had entered the Low Countries with an army, which bore down all opposition. He soon conquered Belgium; he made himself master of Franche Compté, and was fast extending his dominions on every side, when the Triple Alliance, concluded at the Hague in 1669, arrested his ambitious career. Irritated by the share which Holland had taken in this transaction, Louis made great preparations for revenge. The profligate ministry of our Charles II. was hired to support his views; and in 1672, he crossed the Rhine at the head of an immense army. Basely deserted by their natural ally, agitated by internal factions, the Dutch had nothing but a few undisciplined troops, and a general scarcely arrived at manhood, wherewith to oppose the progress of 130,000 veterans, led on by Condé, Turenne, and Vauban. The issue could scarce be doubtful. Louis overran the country in a few weeks; and Amsterdam was soon the last asylum of Dutch liberty. The De Witts proposed surrendering, but the States, with their young general, William, Prince of Orange, at their head, determined on a braver expedient.* Preferring independence to every other advantage, they opened the sluices of their sea-dykes; and Amsterdam once more became an island of the ocean, from which it had been gained. The king returned into France; his generals retired out of Holland; and before the triumphal arch at the gate of St. Dennis, in honour of his *conquest*, was completed, Louis possessed no foot of ground within the conquered territories. Far from yielding, the Dutch in their turn became aggressors; and their young prince, now appointed Stadtholder, ever henceforth continued the unwearied and successful adversary of all the covetous schemes of Louis. By his efforts the present war was ended in 1679; and when he mounted the throne of England, his augmented power still thwarted the increasing projects of France. In 1697, the treaty of Ryswick concluded a new war of eight years,—in the conduct of which he had been indefatigable, in the result of which he was superior; and before his death, he had prepared the materials of that coalition which, under Marlborough and Prince Eugene, brought Louis to the brink of ruin.

The peace of Utrecht saved Louis from absolute destruction, and consigned Belgium to the throne of Austria, that of Spain being now filled by a Bourbon. The Dutch had exerted themselves vigorously in all those quarrels; but from this period their internal prosperity began to languish, their political importance gradually to lessen. The English had acquired their arts and manufactures, and almost entirely supplanted their East India commerce. The American colonies, added to this, gave the English navy an irresistible preponderance. Holland still continued diligent and contented; but the rise of neighbouring nations had eclipsed its power. About the middle of the last century, it was farther threatened with the calamities of foreign invasion. When Maria Theresa's right to the imperial throne was disputed in 1740, the Dutch had taken up her side; the French that of the Elector of Bavaria. During the contest, Louis XV. had penetrated into the Netherlands: and the Maréschal de Saxe had conquered Belgium for him. In 1748, the same general made an attack on Holland. Bergen-op-Zoom had fallen, Maestricht was falling; and the Dutch barrier must have been forced, had not the treaty of Aix-la-Chapelle, which restored Belgium to Austria, while it secured the deliverance of Holland, put a stop to hostilities.

The Dutch took no part in the seven years war. A long period of outward tranquillity was only disturbed by contests between the people and the Stadtholder, whose office had been declared hereditary in the Orange family in the year 1747. The French Revolution, and the victories of Dumourier, took Belgium from Austria in 1792; it was recovered next summer, but the recovery was only for a year, and confirmed the victors in their conquest. Those apostles of change were eagerly welcomed by the Dutch people soon after. But the latter had quickly reason to repent of this predilection. The French oppressed Holland with every species of tyranny; even Louis Buonaparte, for whom it had been erected into a kingdom, gave it up in despair. Various attempts to relieve it failed, till at last, in 1814, the successes of the allied sovereigns put the Low Countries into their hands. The British cabinet accomplished its often projected scheme; Belgium was united with the seven provinces into the Kingdom of the Netherlands; and the Prince of Orange, who had taken refuge in England, now ascended the throne, where he has since continued undisturbed.

The kingdom thus newly formed extends over a space of about 24,000 British square miles, 13,400 of them being Belgic territory, the rest Dutch; and contains a population of 5,226.000 inhabitants, which, (excluding the military,) are distributed among the various provinces as follows.

Holland, . . .	750,000
East Flanders, . .	602,000
West Flanders, . -	521,000
Hainaut, . . :	431,000
South Brabant, . .	366,000
Liege, ...	355,000
Limburg, . . .	393,000
North Brabant, . .	252,000
Antwerp, . . .	250,000
Gelderland, . . .	244,000
Luxemburg, . . .	220,000
Friesland, . . .	177,000
Namur, . . .	157,000
Overyssel, . . .	148,000
Groningen, . . .	136,000
Zealand, . . .	112,000
Utrecht, . . .	108,000
Dronthe, . . .	47,000

The resources of the Netherlands, so long in a declining condition, have not yet had time to recover perceptibly. The annual revenue scarcely exceeds seven millions Sterling; and the expenditure fully equals it. The navy, which could once cope with that of England, has now shrunk into 12 ships of the line, with 24 frigates, and costs only 500,000*l.* a year. An additional 2,000,000*l.* of the national income is devoted to support a military establishment of 50,000 regular troops; the services of religion all paid from the public treasury, require 270,000*l.*; and a government debt of 140,000,000*l.* consumes nearly all the rest. The interest of the latter is moderate, or the country could not bear it: at 2 or 2½ per cent. its amount does not reach far beyond 3,000,000*l.*

Fifty thousand soldiers may seem a force disproportionate to the means of so small a state. They are rendered necessary, however, by the long and defenceless frontier of the kingdom, and by the number of colonies yet subject to it in various quarters of the world. None of those settlements is at present very flourishing or important: some are in a state of permanent decay. In Asia, there are Java, with the lesser governments of Amboyna, Ternate, Malacca, Macassar, and some factories on the coasts of Coromandel and Persia; in Africa, thirteen small forts on the Guinea coast; in the West Indies, Surinam on the mainland; Curaçoa, St. Eustatius, and St. Martin. Demerara, Essequibo, and Berbice, still permitted to trade with their mother country, are now under the dominion of Great Britain.

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* It is mournful to add, that this heroism of the Dutch was tarnished by the murder of Cornelius De Witt, and of his brother John, one of the greatest characters whom Holland or Europe has ever produced. They were massacred by the populace at the Hague in the most brutal and barbarous manner.

The political machinery by which those resources are managed, the form of government in the Netherlands, bears a close resemblance to that of Britain. A king possessed of all the executive authority; two houses of parliament possessed of all the legislative; the sovereign's inviolability; the responsibility of his ministers,—sufficiently point out the model according to which the whole has been constructed. At the same time, several weighty distinctions occur; so weighty, indeed, as to render this general similarity more formal than substantial. One leading distinction is the existence of provincial States, whose office it is to superintend the execution of the laws in their several districts, the expenditure of local magistrates, of religious functionaries; to take charge of the public works,—and, what is more important than all, to elect the members of the lower house of Parliament, a third of whom are thus changed annually; the States themselves being filled up by the people. This lower house of Parliament, so differently nominated, differs equally from our House of Commons in its functions and dignity. The members accept a petty salary, (220*l.*;) they can originate no motion; their number is small;[*] their influence comparatively inconsiderable. The upper house is still more strongly contrasted with our House of Lords. The Belgic *Peers* (between 40 and 60 in number) are not hereditary; they are nominated by the king for life; can bring in no bill on their own authority any more than the Commons; and, like them, receive a paltry wage (270*l.*)

The crown being thus invested with the power of regulating the deliberations of its poor and feeble Parliament, and excluding all importunate discussions, the popular branch of the Belgic government has but a slender influence, compared with that of the British: the mode of its election, the character and rank of its members, must alike conspire to render its limitation of the sovereign's proceedings feeble at any time; altogether ineffectual, if the sovereign were enterprising and ambitious of arbitrary power. The Orange family, however, shows no such sinister desire; a system of equal laws is administered by judges appointed *ad vitam aut culpam;* the taxes are not more heavy than is seen to be indispensably necessary; the press is free; and the people feel no inclination to repine at their condition.

They are remarkable, indeed, for their quietism in regard to politics; and a similar principle now extends also to religion. In the Netherlands, there is, properly speaking, no established religion, the followers of every sect being eligible to all offices in the state, and the preachers of every sect not only tolerated, but paid by the government funds. In the northern provinces, Calvinism is the prevailing doctrine: and the Court is of the same persuasion. The Catholic creed prevails in the southern provinces; in the whole kingdom, its followers outnumber the Protestants in more than the proportion of two to one. But the wealth of either church is small, the salary of a clergyman seldom amounting to £200, frequently bordering on £70: and the government, extending its protection to all ministers of religion indiscriminately, is enabled to secure the adherence and profit by the influence of all.

In regard to education, there is a rather liberal provision in the Netherlands. Parish schools have long been established in Holland, and an additional arrangement renders them more effective than elsewhere. There is a classification introduced among the schoolmasters of Holland. Four ranks are settled by law; no one is allowed to begin teaching till he has enrolled himself in one of those ranks; and two special commissions exist in each province for examining the qualifications of an applicant, and issuing his license to give instruction in the prescribed branches, if his trial prove satisfactory. In Belgium, without any parochial establishment, a competent school-master is yet generally to be found in every village. The higher departments of learning, the *four languages*, as they are called, Latin, French, German, English, with the elements of mathematics, rhetoric, and some minor accomplishments, are taught in the *royal schools* in most of the principal towns. There is a military academy at Dort, a naval one at Sluys; and the religious bodies have in many cases seminaries of their own. To complete the system, there are six universities; that of Leyden, that of Utrecht, the smaller though older one of Groningen, that of Louvain, *re*-opened in 1816 by a royal charter, which also created two new ones, that of Ghent, and that of Liege. Some of those establishments were once flourishing and renowned; they are now but poorly attended. The professors have participated imperfectly in the modern progress of science; their lectures are monotonous, and still delivered in Latin.

The Netherlands, with all its apparatus for education, is not an intellectual country. It has no national literature—none current among its people, or at all known to foreigners. The Dutch language is unfavourable to this purpose; and the Flemish, a kindred dialect of the German, and differing from the former chiefly in accent, is not more so. Vondel is almost the only native poet of Holland. He lived towards the end of the seventeenth century, in the humble capacity of a tailor, and wrote tragedies, which, in spite of their rude barbarous extravagance, are said to display gleams of a high dramatic genius. This mental poverty, however, proceeds from no want of faculties in the people. The telescope and the art of printing, are Dutch inventions. In former times, Holland, if it had no national literature, was inferior to few countries in any of those departments which depend on the exercise of a just intellect, and patient observation. Erasmus and Grotius, in moral science, Huyghens, Boerhaave, Swammerdam, Leuwenhoek, in natural, are universally known. The intellectual fame of the southern provinces, again, rests chiefly on their painters. It is unnecessary to do more than mention the names of Rubens, Van Dyke, Rembrandt.

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[*] It is 110 only; 55 are chosen from the northern province, as many from the southern—in the following proportions:

North Brabant,	7	Friesland,	5	Limburg,	4	Hainaut	8
Gelderland,	6	Overyssel,	4	Liege,	6	Namur,	2
Holland,	22	Groningen,	4	East Flanders,	10	Antwerp,	5
Zealand,	3	Dronthe	1	West Flanders,	8	Luxemburg,	4
Utrecht,	3	South Brabant,	8				

Belgium has produced authors, too, though in a smaller number. Lipsius, well known to classical scholars, was a native of Brussels. Froissart and Philip de Commines were both Walloons, though their birth places are now included in France. At present, the Netherlands are not without many men of cultivated understandings, who are useful and admired at home; but their fame hardly extends to other countries; and the great lights of Europe must all be sought for elsewhere.

See Watson's *Histories of Philip II. and of Philip III.;* Schiller's eloquent and philosophial fragment, the *Geshicte des Abfalls der vereinigten Neiderlande;* Voltaire's *Siècles de Louis XIV. et de Louis XV.;* Raynall's *Histoire du Stadthouderat.* See also Mitchell's *Travels in Belgium;* Boyce's *Belgian Traveller;* Reichard's *Guide des Voyageurs*, § PAYS BAS.

NEVA. See RUSSIA, and NAVIGATION INLAND.

NEUCHATEL, or NEUFCHATEL, anciently *Neocomum*, or *Novum Castrum*, is a town of Switzerland, situated on the western side of a lake of the same name, and the capital of the principality of Neuchatel, belonging to the king of Prussia. The town stands on the declivity of a hill on the banks of a torrent, called the Seyon, which rises in the Val de Ruz, and often occasions great devastations. The town itself is extremely irregular, but the houses are excellent, and the streets clean. The town-house is a splendid structure, having a pediment in front, supported by eight noble Ionic columns. Four female figures are sculptured on the pediment. The back front has a pediment supported by Doric pilasters, and the lower part is rustic work. The hospital is a large and neat building, bearing the inscription of *Civis Pauperibus.* Besides the hospital, and in front of the town-house, is the Maison des Orphelins, which is also an excellent building. The cathedral church, which is by no means elegant, was built in 1164, by Bertha, wife of count Ulrich, of Vinelz. It contains the sepulchral monument erected by Count Louis of Neuchatel to his family, which became extinct in his person in 1373. This monument, which is 15 feet high, contains the statues of nine counts and four countesses. In the centre of the space before the church, is the sepulchral stone of the reformer, William Farel. The Chateau, the residence of the ancient princes of Neuchatel, is near the cathedral, and is now the seat of the public offices. The granary and the barracks are large buildings. The lodge belonging to the free masons, is a neat little building. In coming from Yverdun, we enter the town by a gate, where there is an old tower, and the appearance of old walls. In leaving the town to the north, there are many splendid houses belonging to individuals.

The town of Neuchatel has been under infinite obligations to two public spirited individuals, M. David Pury, and the late M. Pourtales. The first of these gentlemen, who had made an immense fortune in trade in England and Portugal, gave, between the years 1778 and 1786, to his native town, about a million of livres. He died at Lisbon in 1786, and left to Neuchatel all his fortune, to the amount of four or five millions of livres, to be applied to the improvement of public instruction, to the erection of a town-house, an infirmary, and other public establishments, and to the embellishment of the public walks. His portrait is placed in one of the apartments where the government assembles, and his bust in the new town-house. In 1807, M. Pourtales, whose son, Count Pourtales, now inherits his fortune, his talents, and his amiable dispositions, consecrated a sum of 600,000 livres to build a house of charity.

The promenades on the banks of the lake are very fine, and from various houses on the declivity of the hill, there are magnificent views of the western ridge of the Alps seen across the lake.

The lake of Neuchatel is 9 leagues long, and 2 broad between Neuchatel and Cudrefin. It is about 400 feet deep, and its surface is 186 feet higher than that of the lake of Geneva. According to Saussure, its absolute height above the sea is 1320 feet, and according to Tralles, 1340. The height of its level varies about 7½ feet. The lake abounds with fish.

The principality of Neuchatel and Vallengin contains 4 towns, and 64 villages; and, in 1784, the population was 31,576 subjects, and 9704 aliens. The productions of the territory are, red and white wine, fruits, corn, hemp, and flax. Its extent is from 11 to 12 leagues long, and 5 or 6 broad, and it is composed of 6 or 7 vallies. The town of Vallengin is about a league from Neuchatel. It stands in a high valley on the Jura, and the road to it extends along a steep and beautifully wooded glen, at the upper end of which is the village, with its old Chateau, (now a prison,) most beautifully situated on an eminence, having one of the turrets of its outer wall covered with ivy. There are several saw-mills in the village, and the whole appearance of it is singularly picturesque. About a mile to the south of the village stands Bussy, the hospitable mansion of Count Pourtales. See the article LOCLE.

NEVERS, a town of France, and principal place of the department of the Nievre. The town is situated at the junction of the Nievre and the Loire, both of which are crossed by bridges. One half of the fine stone bridge over the Loire was carried away many years ago, and is replaced by one of wood, which existed in 1814. The part of the stone bridge which remains is handsome, and has six arches, through which no water runs. The wooden half consists of ten arches. There is a bridge of three arches over the Nievre, which runs with great obliquity into the Loire. The principal public buildings are, the cathedral church, and the palace of the ancient dukes of Nivernois. The church is a large and elegant Gothic building. The large tower is a piece of fine Gothic architecture, ascended by 372 steps, and it has at each angle hexagonal buttresses, highly ornamented with statues. The body of the church is connected with three side aisles by 23 flying buttresses. The choir is adorned with eight pieces of tapestry. On the floor of the house is a fine meridian line and dial, the hour upon which is indicated by the light which passes through an aperture in the wall.

The ancient Ducal Palace, now the Maierie, and the Palace of Justice, is a tolerably neat building, with two towers at each end, and one in the middle, with seven tier of windows. The coats of arms upon it were all broken off during the revolution. The former residence of the bishop was, in 1814, that of the prefect of the department, and is a handsome building. Besides the buildings mentioned, there is an hospital, barracks, a lofty gate, and the church of St. Peter's. The convent of St. Mary is a quadrangular building with a square court. The boasted manufactory of enamel at Nevers is nothing more than the blowing of glass toys with the blow-pipe. There is a foundry of cannon about two miles to the east of the town. Population 10,150.

NEVIS, one of the leeward Caribbee islands, is a beautiful little island, about eight leagues in circumference. It consists of a single mountain, rising by an easy ascent from the sea to a summit, which has the appearance of a crater, and contains a hot spring, strongly impregnated with sulphur. The productive land in the island is about 4000 acres; and sugar is its only staple production. It is divided into five parishes; Charlestown is the seat of government and the port of entry, and there are other two shipping places, called Indian Castle and New Castle.

The black population is about 10,000, and the whites amount to 600. The English were first established in Nevis in 1628, under Sir Thomas Warner.

The following articles were imported into Nevis in 1806.

	From Britain.	From American States.
Corn,	5035 bushels	14,433 bushels
Bread flour	2180 cwt.	8,682 cwt.
Beef and pork,	21 barrels	157 barrels
Butter,	326 firkins	54 firkins
Oak and pine boards,	240 feet	578,000 feet
Shingles,		688,000 number
Staves,		201,000 number

West long. 62° 3′, north lat. 17° 14.′ See Edwards's *History of the West Indies*, vol. i. and Gray's *Letters from Canada*.

NEWARK, a borough and market-town of England, in the county of Nottingham, is finely situated on the river Trent, near its junction with the Devon. The houses, which, though small, are neat and well built, are arranged in two parallel streets, extending nearly E. and W. and crossed by other two. The streets are well paved and lighted; and the market-place is a remarkably spacious and handsome square. The principal public buildings are, the church, the town-hall, and the castle.

Population in 1811, Houses 1465, and 7236 inhabitants.

See Dickinson's *Antiquities of the Town of Newark*, Edit. 1806; and the *Beauties of England and Wales*, vol. xii. part i. p. 226.

NEW BEDFORD, a sea-port in Bristol county, Massachusetts, on a small inlet of the sea. The harbour is safe and commodious, being completely land-locked by Sconticut Point on the east, Clarks Neck on the west, and a small island.

The inhabitants are active and commercial, own a very considerable tonnage of shipping, and are largely employed in the whale and cod fisheries. Their exports are of such commodities as are obtained by such pursuits. Fish, whale oil, spermaceti, and candles.

This town contains a bank, an insurance office, several places of public worship: its population in 1820, 3947. In 1810, New Bedford and Fairhaven contained 5651. In 1820, the latter comprised 2733, and both places taken together 6680, yielding an increase of 1029 in 10 years.

DARBY.

NEWBURY, a town of England, in Berkshire, is situated on the river Kennet, which runs through the town. The principal streets, which are spacious and well paved, have the shape of a Y, the angles branching off from the market-place, and the foot of the letter being formed by the village of Speenhamland. The houses are mostly built of brick. The church is a plain Gothic structure; and the town-hall is a handsome building, erected over the market-place, and near the bridge over the Kennet. Newbury had once an extensive manufacture of woollen cloth, but serges are the only articles now made. The trade of the place has been greatly increased by the navigable canal to Reading, and will be still further extended by the Kennet and Avon canal. Very fine peat is obtained near the town. Population in 1811, 965 houses, and 4275 inhabitants. See *Beauties of England and Wales*, vol. i. p. 110.

NEWCASTLE-UPON-TYNE. This large, rich, and populous sea-port, is finely situated on the northern bank of the Tyne, at the distance of about nine miles from the entrance of that river into the German Ocean. The town is itself, including a small rural district, a country; so that to speak of it as being *in* the county of Northumberland, although usual, is scarcely correct. Its principal suburb, moreover, Gateshead, is in the county palatine of Durham; but will in this article be considered as making part of Newcastle. Indeed, as the river, although broad and rapid, is in this part of its course crossed by a bridge, at the south end of which, opposite to Newcastle, Gateshead lies, the latter place has no more claim to separate consideration, than Southwark has to be disjoined from London in a general description of the British capital. The extreme length of Newcastle, from Barras Bridge at the north end of Percy Street to the end of Gateshead on the Durham road, is little less than two miles; its breadth, from Skinner-bourn on the south-west to Ouse-bourne on the west, about a mile and a half. Within, however, a circumference that should seem to be indicated by these admeasurements, much vacant ground, especially in the north-eastern quarter, would be included. Still the population of Newcastle, with Gateshead, is, at the time of our writing, about 50,000, of which number nearly 13,000 are supposed to belong to Gateshead. We speak with a degree of uncertainty, because the results of the government census now taking, (1821) have not, as respects this town, been yet made fully known. The public journals have, however, announced, that in the three parochial districts of St. Nicholas, St. John, and All Saints, 27,898 inhabitants have been found, besides 3029 in the township of Byker, a dependency of the last named parish, and adjoining to the eastern suburbs, itself constituting indeed, in part, a suburban appendage to the town. Thus have we a population of, the parochial district of St. Andrew and the whole of Gateshead excluded, 30,927. In 1811, these excluded parishes contained 13,566 souls, a number which Gateshead alone is estimated very nearly to contain at present, and which, added to the already ascertained population of Newcastle, would raise it to about 44,000. Add to the latter, say 6000, for St. Andrew's parish, which, ten years ago, contained 4784, and you have, as the entire population of Newcastle and its dependencies, 50,000.

The situation of Newcastle, although fine, and on the whole favourable for trade, is in some respects inconvenient. The ground on which it is itself built, as well as that occupied by its principal suburb, Gateshead, rises so swiftly from the river, as to impart a painful degree of steepness to some of the chief streets. This is especially the case with Dean Street and the Side. Great improvements have however been made of late years in the opening of new and less inconvenient avenues; besides which, much of Newcastle is built on very nearly a level.

See Bourne's *Newcastle;* Brand's *History and Antiquities of Newcastle; Beauties of England and Wales*, vol. xii. pt. 1.; Scott's *Border Antiquities*, &c. (vv.)

NEWCASTLE-UNDER-LINE, a borough and market town of England, in Staffordshire, is pleasantly situated on the Line, a branch of the Trent, and derives its name and origin from the New Castle, erected by the Earl of Lancaster in the reign of Henry III. in the centre of an extensive pool.

The town consists of several broad and well paved streets. The houses display a superior richness of architecture, but many of them are low and thatched. The appearance of the town is partly injured by the market place being situated in the centre of the principal street.

The population of the burgh in 1811 was, Houses 1245, Inhabitants 6175.

See the *Beauties of England and Wales*, vol. xiii. part 2. p. 982.

NEWFOUNDLAND, an island on the east coast of America, opposite the gulf of St. Lawrence, is separated from the Continent on the north, by the strait of Bellisle, about 21 miles wide. It is of a triangular form, extending from 46° 45′ to 51° 46′ north latitude, and from 52° 31′ to 59° 40′ west longitude. The length is about 380 miles, the breadth from 40 to 287, the circuit 900; and the surface is estimated at 35,500 square miles.

The shore of this island is lofty, desolate, and rocky; but its serrated structure renders it abundant in excellent ports. The whole circumference of Newfoundland is indented, at intervals of two or three miles, by deep bays, having generally a smooth bottom, and a rivulet of pure fresh water at the head. It is in such situations the inhabitants have built their hamlets; their fishing-craft being secured among the rocks. The interior of the country has been little explored; the wetness of the soil in summer, the coldness of the air in winter, rendering this a difficult and perilous undertaking: but what little of it has been viewed, is not found more hospitable than the coast was inviting. A multitude of small lakes are observed, with copious marshes around them; hills of considerable elevation, scantily clothed with sorry birches or fir-trees; and spaces between, which, if not drenched with moisture, are frequently stretched out into plains of considerable size, bearing nothing but a few stunted shrubs and a little heath, among the rocks which cover them. Almost the only practicable mode of travelling is by sledges on the frozen rivers.

The climate of Newfoundland is of a character with its soil. During great part of the year, the south-east, the only inhabited portion of the island, is enveloped in almost perpetual vapours; ships crossing the Great Bank are obliged to ring bells, lest they fall foul of each other; and the fortress of St. John's keeps firing a gun every half hour, to prevent them from running ashore against the rocks. The penguins of Bacalao island are protected under a penalty by law, because their cry answers a similar purpose. In winter the cold is rigorous; the whole country is ice-bound, inaccessible to vessels, and beaten with whirlwinds of sleet and snow, from which, even when congealed, the breezes often load themselves with thousands of icy spiculæ, so minute that they penetrate the smallest aperture, and greatly augment the discomforts of the season. Yet in the absence of these *frost-smokes*, as they are called, a Newfoundland winter is said to be less fierce than a Canadian one, and has some beauties peculiar to itself. The moon and stars shine with a lustre unknown in Europe; and the northern lights are often exhibited during the calm frost in all their brilliancy. About the commencement of April some symptoms of thaw display themselves; and a few days completes the process. As in Siberia and such other regions, the snow is melted both from above and below: it soon yields to this double agency, and impetuous torrents, loaded with half dissolved fragments, and every kind of *debris*, rush headlong towards the coast, from all points of the island. At the same period, thousands of floating masses of ice arrive from Davis' Straits; they surround the shore on every side; they move in every direction; and their mutual shocks, aided by the agitation of a turbulent sea, with the deluge flowing from the land, produce a confusion which resembles chaos. Sometimes a strong *north-wester* will at once recongeal every thing, and bring winter back again with new bitterness. Before June, the summer, without any spring intervening, has arrived. The air is now hot to suffocation, and infested with musquitoes. About the middle of August, the weather begins to be moderate; some days are even said to be delightful. They are of short continuance: before the end of October, the fogs, never long absent at any season, have resumed their empire steadily; and this obscuration of the sun, the deeper hue and the harsher roaring of the sea, the prevalence of cold and snow, announce the approach of winter.

Of indigenous productions, Newfoundland exhibits no great variety. Its timber is not abundant or valuable. The principal use of it is for fuel and fishing-stages. Some attempts were made at one time to construct ships of the larger trees, which, it is true, occur in no great quantity; but these vessels obtained, from seamen who had tried them, the ominous epithet of *Newfoundland coffins:* their utmost period of duration was seven years. The native animals of the island, are bears, otters, beavers, red foxes, which are hunted in the winter season for their skins; and herds of deer, which are hunted for an additional reason. A few small horses are reared by the inhabitants; and some black cattle find a precarious livelihood during summer among the woods, returning home of their own accord at the beginning of winter, or every evening, if they have young. Goats are numerous, and chiefly supply the people with milk. The web-footed dog of this island is celebrated for his aquatic powers; he serves in his own country frequently in the additional capacity of a beast of draught. The common opinion of his being the mongrel of a wolf and a European dog appears to be erroneous. He resembles the Greenland dog in several respects, and seems to belong to a distinct species of his own. The animal commonly met with in England under this name is but half-bred.

Agriculture, it may well be supposed, can make no progress in such a soil and under such a sky. The artificial productions of this island are not more abundant than its natural. Potatoes are almost the only class of European vegetables, which the people have succeeded in raising properly. They constitute a most valuable, though insufficient portion of their ordinary food. Oats, or even wheat, will flourish during the warm months, but they do not arrive at perfection. Turnips, peas, sallad, lettuce of various kinds, can be produced in gardens; but the supply of them is so small, that even the common dandelion is an object of desire. Melons and cucumbers are occasionally raised in hot-houses.

No minerals have been discovered here, though coal is by some thought to exist in considerable quantities. The *gold ore* of the early navigators proved to be a species of pyrites. But the most valuable mine of Newfoundland consists in the produce of its waters, "like which," as Bacon said concerning it, "of all the minerals there is none so rich." Besides abundance of salmon in its rivers, the shores of this island are frequented by numerous shoals of capelins, herrings, mackerel, and, above all, by enormous multitudes of cod, the taking and curing of which gives employment to above 100,000 persons. The Great Bank, where they are principally found, lies to the south-east of the island, and measures not less than 330 miles in length, and 75 in breadth; the water on it, from 15 to 60 fathoms deep, being every where peopled by those fishes, which, though millions of them have been taken annually, for nearly three centuries, have not yet sensibly diminished in number. In regard to the hands it employs, Newfoundland is by far the greatest fishing station in the world; and though no satisfactory estimate appears to have been formed of the exact quantity cured there of late years, it is known immensely to exceed the produce of any other fishery. Loffoden, in Norway, probably does not bear to it a higher proportion in this respect than that of 1 to 5.*

The ships intended for the fishery on the south-east coast, arrive early in June. Each takes her station opposite any unoccupied part of the beach where the fish may be most conveniently cured, and retains it till the end of the season. Formerly the master who arrived first on any station was constituted *fishing admiral*, and had by law the power of settling disputes among the other crews. But the jurisdiction of those *admirals* is now happily superseded by the regular functionaries who reside on shore. Each captain directs his whole attention to the collection of his own cargo, without minding the concerns of his neighbour. Having taken down what part of the rigging is removeable, they set about their laborious calling, and must pursue it zealously. Their mode of proceeding is thus described by Mr. Anspach, a clerical person, who lived in the island several years, and has since written a meagre and very confused book, which he calls a *history* of it.

"The boats used for this purpose vary in their size and in the number of their crews: some having only two hands, and these frequently boys and girls, merely old and strong enough to handle the line. Most boats, however, have four men, each with one line on each side of him, and these lines have two hooks; so that in these boats there are no less than sixteen hooks in constant employment. Each hook is furnished with such bait as the season affords; namely, first the entrails of the fish caught with jiggers; next herring, mackerel, lance, capelin, squids, or young cod; and in default of these, the flesh of sea-fowl.

"The boat having taken her station on a ledge, or other shoaly ground, each line being fastened on the inside of the boat, and the hooks baited, the man sits at an equal distance from the two hooks that are committed to his care, moving them from time to time; as soon as the least tightness or motion is observed in the line, it is drawn up with all possible speed, and the fish thrown into the boat, where the hook is then disengaged from its mouth; if it is of a large size, it is seized, as soon as raised to the surface of the water, with a gaff or large hook fixed to the end of a pole, in order to prevent the disappointment often experienced in consequence of the fish, even when within reach of the hand, either disentangling itself from the hook by the excessive vivacity of its motions, and wideness of its mouth, or breaking the line, and disappearing at once with the hook and bait in its gills.

"When a sufficient quantity of fish has been taken to load the boat, it is then carried to the shore, in order to be cured; this must be done within a certain time not exceeding eight-and-forty hours, otherwise the fish will lose of its value in proportion to the length of time it is kept without splitting.

"The place where the operation of curing the cod-fish is performed, is a *stage*, or covered platform, erected on the shore, with one end projecting over the water, which is called the *stage-head*, and which is fortified with stouters or very strong shores, to prevent the stage from receiving any damage from ships or boats; it has also longers fixed horizontally at intervals, like so many steps, to facilitate the ascent to the stage. On the fore-part of this platform is a table, on one side of which is the *cut-throat*, who takes the fish, cuts with a knife the throat down to the nape, and then pushes it to the *header*, on his right hand; the latter takes it in his left hand, and with the right draws out the liver, which he throws through a hole into a cask under the table; next the guts, which he throws through the *trunk-hole*, in the floor of the stage, into the sea; then fixing the neck of the fish to the edge of the table, which before him is semicircular and sharp, he presses upon the neck with his left hand, to which a thick piece of leather, called the *palm*, has been fastened for that purpose, and with the right gives the body of the fish which is uppermost a violent jerk, which pushes it to the *splitter* opposite to him, while the head thus separated falls through an opening into the water. This operation requires such violent exertion, that besides the palm with which his left hand is armed, the seat on which he is sitting has a strong round back, which assists in collecting all his strength for the effort necessary to separate the head from the body of the fish.

"The splitter, then taking the fish with his left hand, cuts it with the right, beginning at the nape down by the sound bone to the navel; and giving the knife a little turn to keep as close to the bone as possible, he continues cutting to the end of the tail; then raising the bone with the knife, he pushes the fish so split into the drudge-barrow, and the sound bone into the sea through an opening close to him in the stage floor. When the barrow is full, it is immediately carried to the salter, another being put in its place. This process of splitting is performed with considerable rapidity, though with the utmost care, because the value of the fish depends in a material degree upon its being correctly performed; if ruffled by frequent or interrupted cuttings, the fish would be disfigured. The tongues and sounds are sometimes reserved, either for domestic uses or for sale; in which case they are thrown aside and immediately taken up by some other person, so as not to give the least interruption or hindrance to the work performing at the table.

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* See Von Buch's Travels in Lapland.

"At the opposite end of the stage stands the *salter*, who, as soon as the drudge-barrow is brought to him, takes out the fishes one by one, and placing them in layers on one side of the stage, spreads on each some salt with his hand, taking particular care to apportion its quantity to the size of the fish and the degree of thickness of its several parts. This operation, which is continued until the *bulk* is of a proper size, requires particular attention, because, if the bulk is too high, the pressure of the fish in the upper layers will necessarily injure those in the lower layers. The province of the salter demands a perfect knowledge of the business, and considerable experience and judgment, for every thing now depends upon him for the value of the whole voyage. If there is not a sufficient quantity of salt put to the fish, it will not keep; if there is too much, the place where the excess is will look dark and moist,—when exposed to the sun, it will be parched up, and when put back, it will become moist again, and break in the handling of it; whereas, fish properly salted, when dry, will be firm, and may be handled without breaking. The defect occasioned by an excess of salt is known in Newfoundland by the name of *salt-burning*. The proper quantity is about one hogshead of salt to ten quintals of fish; somewhat more, if the fish is not to be dried immediately, but carried away *green* from the place where it is caught.

"The fish, after these primary operations, must remain five or six days in bulk, before it has sufficiently taken the salt; and, after that period, the sooner it is washed the better. For this purpose it is put into washing vats, or wooden vessels, generally seven or eight feet long, three and a half feet wide, and three deep. They first throw in two or three quintals, over which they pour a quantity of sea-water, gradually increasing the quantity of both till the vat is full. They then take up each fish separately, cleaning carefully the back and belly with a woollen cloth, and next lay it in a long even bulk on the stage-floor to drain. They resume the same process, until they have washed such a quantity of fish as they can manage next day. It may remain in drain-bulk no more than two days; if kept beyond that time it will decay in weight, nor will it stand the weather so well on account of the salt getting out of it.

"The next day, or as soon after as the weather permits, the fish is spread out in the open air to dry, head to tail, the open side being exposed to the sun. This is done either upon a beach, or upon the ground, which is called *laying-room;* but more generally upon standing flakes. These last are of two sorts, namely, hand and broad flakes. The former consist of a slight wattle supported by posts, at such an elevation from the ground, that a person standing can conveniently manage and turn the fish. The broad flakes consist of a set of beams, supported by posts and shores, or stout pieces of timber standing perpendicularly under the beams, to which similar pieces are likewise fixed in a sloping position. In some places these broad flakes are as high as 20 or 30 feet from the ground. It is said that a free circulation of air is of considerable service to the fish while drying; hence high flakes are preferable to low ones, or to beaches,—where, besides the want of a circulation of air, the back of the fish is liable to be *sun-burnt*, if spread after the sun has heated the stones. But when the fish is dry, and spread only to make it perfectly fit to be put on shipboard, beach or flake will serve equally well.

"Towards evening of the first day, two or three fishes are placed one over the other, with their backs upwards, to prevent the open side from being injured by the wet or damp. Next morning the fish is again spread as before, and towards evening made into faggots of five or six, proceeding in the same manner, so as to increase the faggots to eight or ten on the third evening, and on the fourth to eighteen or twenty, always with the back upwards, and some larger ones on the top in a slanting position, so as to shoot off the rain or wet that may happen to fall during the night. On the fifth evening the faggots are made much larger; the fish is then considered as safe, and left in that state for a week, or even a fortnight, if there is a want of flake-room for the whole voyage, or the weather happens to be bad. It is next spread out again until about three or four o'clock in the afternoon of the same day, when it is put into large circular piles, in the form of a round hay-stack, with the heads outmost, the backs upwards, and the whole is covered with circular deal frames, or with mats, tarpaulins, or rinds confined by large stones, in order to preserve it from the heavy dews which fall during the heat of summer. It is left some time in that state, then again spread out, and the same day, towards evening, lodged in stores or put on board the vessels. After the fish has been first spread on flakes, four good days out of seven, (considered preferable to four successive good days, because it then works, or, as the fishermen express it, *sweats* better,) will be sufficient to save it from any material damage. As a single drop of rain or fresh water may so affect a fish as not only to injure it greatly, but also to communicate the infection to the whole faggot, pile, or even cargo, the state of the weather is watched with particular attention while the fishes are drying; and these, on the least appearance of a shower, are immediately turned back uppermost. As Newfoundland, during the summer, is subject to sudden showers, the hurry and confusion which this frequently creates throughout the whole place, can hardly be described. It occasions no small annoyance, if happening on a Sunday, while the people are at church. The flakes are then in an instant covered with men, women, and children, busily employed in turning the fishes or making them into faggots; the profits of the whole voyage, the means of paying the debts contracted, and of procuring supplies for the support of the family during winter, may all depend on the exertions of that moment.

"Such is the precarious and uncertain nature of the cod-fishery: at the same time the fatigues which attend it are very great. During the heat of the fishery, the people, under the most incessant hard labour, have scarcely time to eat their meals, and hardly four hours of rest in the four and twenty. In some parts of the coast, the ledges are at so great a distance, that much time is consumed in the passage from their respective harbours and back again; and even in those parts which are more favourably situated, the fish does not always abound equally. It is sometimes found in the north, and sometimes in the south of the island; at other times in the middle of the coast, according as it is driven by winds, or attracted by the smaller fish; so that some fishermen are nearly ruined, while others, more fortunate, make excellent voyages."

Besides this cod-fishery, the produce of which, amounting to upwards of half a million quintals, is preferred in the southern markets of Europe to that of any other, there are fisheries of salmon, herrings, and seals

Of the latter about five thousand are taken annually; their skins and their oil form a considerable export; their flesh is eaten by the inhabitants.

As fishing constitutes the main object for which Newfoundland is visited or occupied, the number of persons to be found on it varies greatly at different seasons of the year. Formerly none except a few poor families passed the winter here; and the governor himself, who was simply the commodore of the squadron appointed to protect the fishing vessels, used to live on shipboard. For a long period, however, the number of wealthy residents has been progressively increasing; a considerable quantity of capital has been vested in permanent establishments; and the villages of Newfoundland are gradually emerging from the condition of bleakness, and impurity, in which they once stood. St. John's, Placentia, Harbour-Grace in Conception Bay, have already the appearance of flourishing colonial towns; comfortable, considering the climate and soil that surrounds them. All three are in the south-east portion of the island. St. John's is the seat of the governor, whose authority also extends over Anticosti, some smaller islands, and the adjoining coast of Labrador. It is fortified by various batteries, which, together with the peculiar security of its position, render it a place of considerable strength. The harbour, one of the finest in Newfoundland, is the general rendezvous where homeward bound ships join convoy. It consists of a bay formed by two mountains, both very steep, the south one almost perpendicular, which bend round towards each other on the eastern side, leaving a small entrance, which is appropriately denominated *The Narrows*. Within this, which some rocks and shoals render a little dangerous, a ship (and only one can enter at a time.) finds smooth and deep water, extending for about two miles inland. The town stands at the head: it is built of wood, like all other towns here; and the houses having generally but one story, make rather a mean figure, and, what is worse, are liable to dreadful calamities from fire. It is fast improving, however: some of the newer parts are even said to be elegant. It has a printing-press, from which a weekly newspaper issues.—Placentia was long a French settlement: both it and Harbour-Grace are greatly inferior to St. John's. The remaining hamlets deserve no mention.

In their manners and character, the inhabitants of Newfoundland display most of the qualities and defects commonly to be found in persons similarly situated. The wealthier order prosecute trade with diligence, and show considerable address and dexterity in transacting their affairs. Refinement or elegance of feeling is, of course, rarely met with. What would be its use, or where would be its place among warehouses of codfish and train-oil? The poorer class are in great part Irish, or descendants of Irish. Like other Irishmen, they are indefatigable in labour, and can endure every privation without lamenting or seeming to notice it. Like other Irishmen, too, they are often irregular and barbarous in their way of life. When a fire breaks out in any of the towns, *conflagration* is not the only evil to be dreaded. Theft is frequent; and St. Patrick's day, among other national festivals, is kept with an overflowing jollity, to which magistrates cannot look forward without apprehension. Some old observances, as that of the *Christmas Log*, are still generally attended to.

A little exuberance in such festivities might well be pardoned in a country where the circle of enjoyments is so narrow. The people toil throughout the summer amid moisture, and musquitoes, and heat: in winter their log-houses defend them but imperfectly from the severities of a worse than arctic climate; and their bread requires all to be brought from Britain or America. Except fish, of which the employment is continual, and potatoes, with a few pot-herbs, the supply of which is inadequate, Newfoundland gives no constant store of food to its inhabitants. The precarious capture of deer rarely brings venison into the market; and seal-flesh is a very imperfect substitute for beef. The only native beverage is a kind of beer prepared from the twigs of the spruce fir: it is said to be palatable. Tea, as well as fish, is used at every meal; or else a decoction of the *wisha capucoa*, or Indian tea, a native herb, which the poorer classes employ instead.

The history of Newfoundland begins with the eleventh century, when Biorn, a *sea-king*, or pirate, of Iceland, was driven thither by contrary winds in the year 1001. Biorn's colony will not detain us long. If they ever did occupy the island, they had become extinct before any traces of their existence had reached the more civilized nations of Europe; and the country required again to be discovered nearly five hundred years after. John Cabot, (Giovanni Gabota,) the well known Venetian agent of Bristol, obtained a commission to make discoveries (at his own cost) from Henry VII.; and during his first voyage, on the 24th June, 1497, came in sight of a headland, to which, regarding it as a lucky omen, he gave the name of *Bonavista* It was that cape of Newfoundland which is still called so. After coasting the American continent as far as Florida, Cabot returned home with various productions of the countries he had visited, and three natives of Newfoundland. "These were clothed in beasts' skins," says Fabian, "and spake such speech that no man could understand them; and in their demeanour they were like brute beasts; whom the king kept a time after; of the which about two years after I saw two apparelled after the manner of Englishmen, in Westminster palace, which at that time I could not discern from Englishmen till I was learned what they were; but as for speech, I heard none of them utter one word."[*]

The *new-found* island was, not long after, visited successively by Cotereal the Portuguese, and Cartier the French navigator. The excellence and the abundance of its cod, which had originally procured it the name of Bacalao,[†] soon attracted fishermen to the coast. Vessels from England, France, Spain, Portugal, continued to frequent it during the whole of the sixteenth century; but no permanent settlement was attempted by any of those nations. The English, to whom it of right belonged to colonize the country, at length exerted themselves, though for a time without success. Sir Humphrey Gilbert, whose *Treatise on the North-west passage*, 1579, late events have again brought into notice, lost both his fortune and his life in this enterprise. A London merchant, named Hoare, had already tried it in

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[*] A few scattered families of these Aborigines still exist in the interior of Newfoundland. They are cruel and suspicious beyond even the usual character of savages; having hitherto rejected every species of intercourse with the settlers, and murdered every white man whom they could lay hold of.

[†] The Indian word for *cod*. *Cabaillaud*, the French name, is formed by transposing it.

1536; and his trial had failed utterly: the ship's crew, to avoid absolute starvation, had been obliged to resort to the most horrible expedients; and even those would not have saved them, had they not been lucky enough to lay hold of a French ship loaded with provisions, which enabled the emaciated survivors to return home. But Sir Humphrey was not to be deterred by their fate, or yet by the unfortunate issue of his own first trial. Sharing the projective adventurous spirit of his half-brother, the famous Sir Walter Raleigh, he determined to make a second and a greater effort, before the six years, during which Queen Elizabeth's patent allowed him to take possession of two hundred leagues round any point he chose to settle on, were expired; and, accordingly, having sold all his estates to equip five small vessels, he embarked with 260 people in 1583. Sir Humphrey reached the bay of St. John's, and took formal possession of the place, in presence of a great multitude of fishermen, who had seemed at first inclined to obstruct him; he also procured some *marcasite*, which Daniel, his "experienced assayer," pronounced to be silver ore; but here all his good fortune ended. Anxious to bring the southern countries also within the compass of his patent, Sir Humphrey prepared to sail in that direction. His crews hesitated to accompany him; they mutinied, and part of them at length returned home. The next occurrence was more lamentable still: one of the three ships which yet agreed to prosecute the voyage was wrecked shortly after the beginning of it in a gale; and above a hundred men perished with her. Disheartened by such a loss, all were decided for steering homewards, and Sir Humphrey at length consented also. He had suspended, not renounced his schemes. "If the Almighty should permit us to reach England in safety," said he, "I will set you out royally in the course of next spring." It was not so determined: Sir Humphrey's ship was missed by her companion one morning,—and never heard of more! She had gone down over night; and this high-minded gallant man, with all his golden hopes, was now swallowed in the deep, and calm as the dullest of his crew.

The death of Sir Humphrey was fatal to his plan; Raleigh being allured from prosecuting it by the more tempting prospects of Virginia and the El Dorado. A third attempt was made in 1610, by a company in which Lord Bacon had a share. The settlers visited Conception Bay; but few of them remained there: and the first permanent colony, worthy of the name, was planted by Sir George Calvert, afterwards Lord Baltimore, in 1623. It consisted of Puritans, like the colonies of New England; and fixed itself at Ferry Low, from which it spread by degrees over all the bays in the south-eastern peninsula. Lord Baltimore gave the name *Avalon* to this tract; and so interested was he in the fate of his colonists, that he sent his son for six years to reside among them. They flourished under his superintendance; and their assistance soon produced a sensible improvement in the English share of the fishery.

Towards the conclusion of that century, their prosperity, and still more their quiet, was interrupted by the neighbourhood of a rival. The French had settled themselves at Placentia (Plaisance) where they had erected a fort; and the jealousy of the two nations, sharpened as it was here by the competition and the contiguity of their pursuits, broke out in continual broils, even when the mother-countries were at peace. During a time of war, in Europe, the settlements never failed to take advantage of a state so conformable to their own habitual feelings; and each harassed the other by continual invasions, captures, and every species of vexation. The treaty of Utrecht (1713) put a stop to such proceedings. The bad posture of his affairs compelled Louis XIV., on that occasion, to admit the prior and preferable claims of England to the whole island: the French evacuated Newfoundland finally, retaining only the permission to fish on a certain small portion of its shores, and liberty to occupy the islets of St. Pierre and Miquelon, with a garrison, or rather police of fifty men, where the fish might be dried. The final conquest of all their American colonies, in the seven years' war, made the French glad to receive back this privilege at the peace of Paris (1763;) they advanced no farther pretensions; and this humble one, again admitted at the conclusion of the late hostilities, now forms their sole connexion with the island. A similar right was also guaranteed to the United States.

Since the expulsion of the French, the history of Newfoundland offers nothing particularly worthy of remembrance. The colonists were favoured with a resident governor in 1728; civil and justiciary courts were instituted among them soon after; and a supreme court was added in 1792: since the middle of last century, when England became undisputed ruler of the ocean, they have rarely been annoyed by the presence of a hostile fleet; their limited class of resources has continued to extend in quantity, if not in variety; and at present the fisheries and trade of the island are supposed to produce an income of not less than two millions annually.

See the Rev. Lewis Amadeus Anspach's *History of Newfoundland*, 1819; and Morse's *American Gazetteer.*

NEW GRENADA, formerly a viceroyalty of Spain in South America, now part of the republic of Columbia. This great country lies between the Atlantic Ocean and Caribbean Sea, and comprises the north-west angle of South America. It is bounded, north by the Caribbean sea; west by the isthmus of Panama and Pacific Ocean; south by Peru; and east by other parts of the republic of Columbia. It extends from the river Tunguragua, about S. Lat. 6°. to the Caribbean sea, N. Lat. 12°.

That part of New Grenada lying along the Pacific Ocean, is composed of a long narrow slip of level land. The Andes mountains rise, however, within a short distance inland, into the highest ridges and peaks known in the world, except those of Gangetic Indostan. Chimborazo, Cotapaxi, and Cayambe Urai, all rise within a short distance from the equinoctial line. The great spine of the Cordileras, or Andes, traverses the country in enormous collateral ridges, with, in many places, very elevated intervening plains and valleys. Quito and Popayan are both situated on these aerial heights. From the Andes the country spreads into immeasurable plains towards the Oronoco.

Near Popayan, the vast ridges of the Andes diverge. One branch continues to the north, and merges into the Caribbean sea near the isthmus of Darien. A second runs nearly parallel to the former, between the rivers Guacaba and Magdalena, and also merges into the Caribbean sea, in the province of Carthagena. A third, and very considerable range, divides the sources of the Magdaline from those of the Orenoco, and terminates by Cape Chichivanas, between the provinces of Santa Martha and Marycaibo.

New Grenada comprises almost every climate, and every variety of soil and mineral and vegetable production. The population is now supposed to amount to about 2,000,000, but it is probable more than three-fourths are Indians. The country is peculiarly favourable to agriculture and commerce; and, under a liberal government, could not but rise to a high state of prosperity, wealth, and power.

NEW-HAVEN, a city of the state of Connecticut, in the county of New-Haven, at N. lat. 41°. 18′. and 72°. 56′. W. long. from Greenwich. This city is situated on a fine bay, formed by the small rivers Wallingford or Quinnipiach, and Mill river. The city is situated on the western side of the bay, about four miles from Long Island Sound.

New-Haven is delightfully situated on a plain, with, except towards the bay, hills, and even mountains, rising in every direction. The city is laid out, in general, with the streets intersecting at right angles; but in the lower part of the city, some of the streets diverge obliquely.

In the centre is one of the finest open squares in the United States, around which are eight more; these nine squares forming the old or original New-Haven. Each square, independent of the streets, is 835 feet on each side. The streets are 83.5 feet wide, and extend N. 32°. 30′. E. and S. 32°. 30′. W. and N. 57°. 30′. W. and S. 57°. 30′. E.

Within the centre square stands the Court-house and Presbyterian Meeting-house. Yale College is situated on the square to the north-west of the centre square.

New-Haven contains Yale College, a Grammar school, four Churches, Court-house, Custom-house, a Jail, two Banks, three Insurance Offices, and an Alms-house.

Several newspapers are published weekly. A religious Magazine is also published monthly. The work most honourable, however, to the science of the people of New-Haven, is the American Journal of Science and Arts, conducted by Professor Silliman.

The houses of New-Haven present the aspect of rural neatness, from the great number of trees which adorn the streets, and from the fine, and, in many parts, extensive gardens, which are cultivated in the rear of the buildings. Many of the private houses are fine, and even splendid edifices, and in general have the appearance of cleanliness and comfort.

On the north side of the city, a large square is laid out for a public burying ground. It is subdivided into squares and walks, planted with trees. The gravestones are, in general, marble; the whole presenting, perhaps, the most exquisite combination of solemnity, taste, and elegance, to be found in the United States.

Yale College deserves particular notice, as being one of the most ancient and efficient seminaries of learning in the United States. It consists of four spacious buildings, a chapel, lyceum, and laboratory.

The medical institution is connected with the college. The former was established in 1813, with four professors, an anatomical museum, and a medical library.

George Gibbs, Esq., in 1811, deposited in Yale College his excellent collection of minerals, which cost, it is said, near 18,000 dollars. The college library exceeds seven thousand volumes.

The officers of Yale College are, a president, nine professors, including four medical professors, and five tutors. The governor of the state, and lieutenant-governor, are trustees *ex officio*, but are associated with six senior assistants, and ten fellows, being clergymen.

The number of students are, in general, about 400. Mr. Morse, in his Gazetteer, edition of 1821, states, that 3478 students had been educated in Yale College, from its foundation to the year 1820, of whom 1884 were then living.

In 1820, a seminary was established at New-Haven, for the education of students intended for the clerical profession in the episcopal church. The superintendance is placed in the hands of the general convention of that church.

The neighbourhood of New-Haven is in a high degree pleasant, well cultivated and diversified. The inhabitants are, in general, polite to strangers, well educated, and of regular morals.

The population of New-Haven, in 1810, was 5772; in 1820, 7147, giving an increase in ten years of 1375.

DARBY.

NEW-HAMPSHIRE. See HAMPSHIRE, NEW.

NEWMARKET, a market town of England, in the counties of Cambridge and Suffolk, is principally celebrated for possessing one of the finest race-courses in the kingdom, where races are held twice in the year, on Easter Week, and in the month of October. The town consists chiefly of one wide street, and the houses, erected partly on the gentle declivity of a hill, are in general modern and well built. Many of the most handsome are the residences of the nobility and gentry who frequent the races. The town contains numerous inns, with excellent accommodation. Two coffee-houses are furnished for the use of Betters. There is in the town two churches, one of which is in Suffolk and the other in Cambridgeshire. The town was twice nearly destroyed by fire, namely, in 1683, when Charles II. his queen, and the Duke of York, attended the races. The damage amounted to about 20.000*l*. The second conflagration was about the beginning of the last century.

The population of the southern side of the town, which is in Cambridgeshire, was, in 1811, 70 houses and 486 inhabitants, and, of the northern side, in Suffolk, 256 houses and 1631 inhabitants, making in all 1917 inhabitants. See the *Beauties of England and Wales*, vol. ii. p. 139

NEW-ORLEANS, the capital, and chief town of the state of Louisiana, stands upon the left bank of the Mississippi river, at N. lat. 30°. and west, from Washington City, 12°. 05′.

New-Orleans is composed of the city properly so called, and several Fauxbourgs, (suburbs,) the principal of which are, St. Mary's, Annunciation, and La Course, above the city; Marigny's, and Broniers, below; and Tremé, and St. John's, in the rear of the city, towards Bayou St. John's.

The city itself is laid out with the streets intersecting each other at right angles. The Fauxbourgs, though in general also regular, deviate in some places. Like all other places along the banks of the Mississippi, the ground upon which New-Orleans stands falls, by a gentle declivity, from the margin of the river, until depressed into a swamp, or overflown flat, in the rear of the town. The city, and all its Fauxbourgs, except those of Tremé and St. John's, stand upon the solid border of land between the river and swamp, the medium width of which, is about 400 yards. The extreme length of New-Orleans along the Mississippi is nearly three miles. The river running opposite in the form of an S. It contains a State-house, Prison, Market-house, Hospital, Principal, or Town-house. A Cathedral, or the Church of St. John's, Ursuline Convent, an Episcopalian, and a Calvinistic church, two Theatres, a Court-house, three Insurance offices, four Banks authorized by the state, a branch of that of the United States, a Custom-house, Navy Yard, Arsenal, Barracks, and one Fort, that of St. Charles, situated between the city proper and Fauxbourg Marigny.

New-Orleans is situated 105 miles above the mouth of the Mississippi, 322 by water, and 156 by land, below Natchez; 1189 below St. Louis; 991 below the mouth of Ohio, and 1935 below the city of Pittsburg.

It is ruled by a mayor and city council, elected by the freeholders.

This city is admirably situated for a commercial depot, having equal facility of intercourse, foreign and domestic. Its markets are excellent, particularly for garden vegetables, and for fruits, both tropical, and from the numerous settlements on the various confluents of the Mississippi. The houses and population are both rapidly on the increase, as may be seen by the following comparative view of its census in 1810 and 1820. At the former period, the city and parish contained 24,552, of whom, above 17,000 were found in the city. In 1820, the number of inhabitants stood thus:

Free white males, - - - - - -	11,675
Free white females, - - - - - -	7,569
Foreigners not naturalized, - - -	1,549
Total,	20.793
Male slaves, - - - - - - - - -	7,331
Female slaves, - - - - - - - -	7,615
Free coloured persons, males, - -	2,835
Females, - - - - - - - - - -	4,326
Total of slaves and free coloured persons,	22,107
Entire population, - - - - - -	42,900

New-Orleans was laid out in the spring of 1717, and named in honour of the Duke of Orleans, then Regent of France, during the minority of Lewis the XIV. It remained in the hands of the French until 1769, when, together with all Louisiana, it was taken posssession of by the Spanish general, O'Reily. It was again given up by Spain to France in 1803, and on the 20th of December of that year given up to the United States, by the French colonial prefect Laussatt.

In the month of November, 1814, a British fleet and army appeared off Cat Island, and on the 16th of November, the United States flotilla of gun-boats were captured in the Pass, between the Malheureux islands and Florida shore. On the morning of the 23d December, part of the British army reached the bank of the Mississippi, at General Villaret's plantation, eight miles below New-Orleans. On the evening of the same day, general Jackson attacked them in their encampment, when a sharp but indecisive engagement took place; both armies claiming the victory. On the ensuing morning, the United States' army took position on Rodriguez's canal, three miles below the city, and that of the British formed its lines one mile still lower down. Partial engagements intervened on the 28th day of December, and on the fifthday of January. 1815, and on Sunday morning, January, 8th, general Packenham quit his lines, and attacked the United States' army in its entrenchments. The former were defeated with great slaughter, with but very little loss on the part of the latter. The British lost about 2000 men, that of the United States' army was only five killed and seven wounded.

On the night of the 18th, the British commenced their retreat on board their vessels, and evacuated Louisiana a few days afterwards.

Darby.

NEWPORT, a large borough and market town of England, in the Isle of Wight and county of Southampton. The town has an elevated and agreeable situation, nearly in the centre of the island. It is watered on the east by the principal branch of the Medina river, and on the west by a small rivulet which flows into the Medina at the Quay, when it becomes navigable for vessels of large burthen. The houses, which are chiefly of brick, and some of them very handsome, are arranged in *five* parallel streets, which extend east and west, and are intersected at right angles by other *three*. In the first plan of the town it was proposed to have had three large squares at the intersection of the streets, as market places for cattle, corn, and poultry; but this has been prevented by various encroachments.

Carisbrooke Castle is about one mile south-west of Newport, and is one of the most ancient and important fortresses in the island. It occupies about 20 acres of ground on a conical eminence, rising above the village of Carisbrooke. Dr. Stukely thinks that it was built by the Emperor Carausius; and about 70 years ago six Roman coins were dug up in a field to the north of the castle. It is celebrated as having been the prison of Charles I.

In 1811 the borough and parish contained 657 inhabited houses, and 3855 inhabitants.

See the *Beauties of England and Wales*, vol. vi. p. 355.

NEWPORT, a post town, and, alternately with Providence, capital of Rhode-Island, five miles from the Atlantic Ocean, and on a small but very commodious bay formed by a projection of Rhode-Island proper, and Connecticut Island. Longitude W. from Greenwich, 71°. 17'.; and E. from Washington, 5°. 43'. Lat. 41°. 29'. N.

The harbour is one of the best on all the Atlantic coast of the United States, opens before the town into a noble circular basin, easy of access, land-locked on all sides, and commanded by the adjacent heights. Goat Island, a small spot of ground at its outer entrance, contains Fort Wolcott and an United States' navy hospital. The harbour is also defended by two other forts—Fort Green, and Fort Adams.

Though much declined from its former comparative importance, Newport is still a flourishing town. The site rises by an elegant acclivity from the harbour, and again declines gradually in the rear, giving the aspect of a delightful swell to the whole place.

Newport contains, a State-house, Market-house, Theatre, public Library, Alms-house, five Banks, two Insurance Companies, eleven places of public worship, four Baptists, two Congregationalists, one Episcopalian, one Friends, one Moravian, one Methodist, and one Jewish Synagogue.

In 1819, the amount of shipping owned in this town, was near 11,000 tons.

The population of the town, and that part of its vicinity included in the township, as it stood in 1810, and in 1820, are exhibited in the annexed table.

Population in 1810.

Free white males,	3,440
do. do. females,	3,837
Total whites,	7,277
All other persons except Indians not taxed,	630
Slaves,	
Total population in 1810,	7,907

Population in 1820.

Free white males,	3,157
do. do. females,	3,606
All other persons except Indians not taxed,	
Total whites,	6,763
Free persons of colour, males,	197
do. do. females,	342
Slaves, males,	7
do. females,	10
Total population in 1820,	7,319

Of these;

Foreigners not naturalized,	38
Engaged in Agriculture,	174
do. in Manufactures,	630
do. in Commerce,	107

The manufacturing establishments in this town and vicinity are numerous and important, consisting of five or six Rum distilleries, one Gin distillery, one Duck factory, and numerous grain mills.

DARBY.

NEWTON, SIR ISAAC, the most celebrated mathematician and natural philosopher that any country has produced, was born on the 25th of December, 1642, at Woolsthorpe, a village in the parish of Colsterworth, in Lincolnshire, about six miles south of Grantham. His father was descended from the oldest branch of the family of Sir John Newton, Bart., and was lord of the manor of Woolsthorpe. They came originally from Newton in Lancashire. His mother, Hannah Ayscough, was of an old family in Lincolnshire. She contracted a second marriage with the Rev. Barnabas Smith, a wealthy old Bachelor, by whom she had a son and two daughters. When Isaac was born, which was three months after his father's death, he was of extremely diminutive size, and two women who were sent to Lady Pakenham's at North Witham, for something for the child, did not expect to find him alive at their return. Mrs. Newton was extremely attentive to his education. She sent him to two day schools at Skellington and Stoke; and, at the age of 12, he went to the great school at Grantham, under Mr. Stolkes; where he boarded in the house of an apothecary, whose brother was usher of the school.

At this school he displayed a very singular passion for mechanical contrivances. By means of little saws, hatchets, hammers, and all sorts of tools, he made models of wood, when his companions were at play; and such was his dexterity, that he constructed a wooden clock, and a good model of a windmill which was erected about that time near Grantham, on the way to Gunnerby. Into this model he sometimes put a mouse which he called his miller, and by means of whose action he could turn the mill round when he chose. He executed also a water-clock, about 4 feet high, with a dial-plate at top for indicating the hours. The index was turned by a piece of wood, which either rose or fell by the dropping of water. The passion of the boy for these mechanical occupations often withdrew his attention from his regular studies; and in consequence of this the other boys gained places above him, till he was roused to outstrip them all by a little extraordinary exertion. The intermission of his mechanical pursuits, which was thus rendered necessary, rather increased than abated his ardour for them. He introduced the use of paper kites among his school-fellows. He made paper lanterns, by the light of which he went to school in the winter mornings; and he frightened the country people by tying them to the tails of his kites in a dark night. He watched too the motions of the sun with great diligence; and by means of pegs placed in the wall of the house where he lived, and marks for the hours and half hours, the time of the day was shown to every person, on what went by the name of Isaac's dial. He had also a great turn for drawing; and, according to the account of Mrs. Vincent, who was niece to the wife of Sir Isaac's landlord, at Grantham, he frequently made little tables and cupboards, for her and her play-fellows. She mentions also his having made a cart with four wheels, in which he could drive himself by turning a windlass.

Upon the death of Mrs. Newton's second husband, she went from North Witham to Woolsthorpe, and recalled Isaac from school, in order that he might give his assistance in managing the business of the farm. He superintended the tillage, the grazing, and the harvest; and, accompanied by a trusty servant, he went on Saturdays to Grantham market to dispose of corn and other articles of agricultural produce. Isaac frequently deserted his commercial charge, left the servant, and betook himself to a garret in the apothecary's house, where he amused himself with some old books, till he received notice that it was time to return. The affairs of the farm did not flourish under our young philosopher's management. The study of a book, the execution of a model, or the superintendance of a water wheel of his own construction, often occupied his attention when the sheep were astray, and the corn treading down by the cattle.

Mrs. Newton, seeing that her son's propensities were not those of a farmer, again sent him to Grantham school. After remaining there nine months, he went to Trinity College, Cambridge, where he was admitted on the 5th June, 1660, in the 18th year of his age. In this favoured situation the peculiar talents of Mr. Newton began to display themselves. The ardour with which he prosecuted his studies, and the rapidity of his progress, attracted the notice of his teachers, and acquired him the admiration and friendship of Mr. (afterwards Dr) Barrow, who was then a fellow of Trinity College. The works which he now perused with avidity were, Saunderson's Logic, Kepler's Optics, the Geometry of Descartes, and the Arithmetic of Infinites of Dr. Wallis. The Elements of Euclid, and the works of the ancient geometers, occupied less of his attention than they were justly entitled to; but he appears to have been carried away by the seductions of analysis, and he afterwards expressed his regret to Dr. Pemberton, "that he had applied himself to the works of Descartes and other algebraical writers, before he had considered the Elements of Euclid with the attention which they deserved." In 1664, Mr. Newton took the degree of bachelor of arts, and it appears, from some of his accounts of expenses, that he bought in that year a glass prism, for the purpose of examining experimentally Descartes' doctrine of colours. There is no reason, however, for believing that he began so early to obtain the results which afterwards excited so much notice, for he was interrupted in the midst of his researches by the appearance of the plague at Cambridge in 1665, which compelled him to quit his studies, and retire to his own property in the country. During the two years which he now spent in the country, his mind, as might naturally have been expected, was absorbed in philosophical speculations; and it was in this peaceful seclusion that he received the first glimpse of those splendid discoveries which have elevated his name above that of all other men, and shed renown upon the country that gave him birth. When seated alone in a garden, the accidental fall of an apple fixed his thoughts on the subject of gravity. In reflecting upon this property of matter, and considering that it seemed to experience no diminution at the tops either of the highest buildings or the loftiest mountains, he was led to conjecture that it might extend far beyond the earth and its atmosphere, and even to the orbit of the moon. In this view of the matter, he considered the moon as nothing more than a falling body, constantly deflected to the earth from the rectilineal path in which it had been projected, and it became an easy matter to ascertain the force of gravity at the distance of the moon, and to determine if it emanated from the same source as that which exhibited itself in falling bodies at the surface of the earth. In attempting, however, to make the calculation, he employed the erroneous but common estimate among geographers, that sixty miles make one degree of the meridian, and having with such imperfect data obtained a result which opposed his theoretical speculations, he concluded that the moon must be influenced by some other course than that which produced the fall of heavy bodies.

At various times after he procured his prism, in 1664, Newton had directed his attention to the subject of optics. He began by grinding lenses in the form of some of the conic sections, with the view of correcting their spherical aberration, and in the belief that this was the only imperfection to which the telescope was liable. His success, however, did not equal his expectations; and he was led to study the nature of light itself, by repeating with his prism some of the experiments made by Grimaldi. The brilliancy of the prismatic colours struck him with surprise, and his attention was particularly fixed on the oblong figure of the spectrum. According to the received laws of refraction, the image of the sun ought to have been exactly circular, in place of an oblong form. This irregularity Newton at first supposed to be only accidental, and in attempting to find its cause, he was led to discover the compound or heterogeneous nature of colourless light, and to determine the different refrangibilities of the coloured rays which entered into its composition. This important discovery explained to him at once the cause of the imperfections of refracting telescopes, and having computed the amount of the error arising from the different refrangibility of the rays of light, he found it to exceed some hundreds of times that which was occasioned by the spherical form of the lenses. By such steps Newton was led to study the reflection of light, and he speedily saw that by means of a reflecting material, capable of being polished as highly as glass, and having an exact parabolic form, he could construct a telescope free from all the errors produced by the compound nature of light.

In 1666 Newton was elected a Fellow of Trinity College, and in the same year he took his degree of Master of Arts. Dr. Barrow, who was now Lucasian Professor of Mathematics at Cambridge, having resolved to confine his attention to theology, resigned his chair in favour of Mr. Newton, who was thus obliged to relinquish for a while his practical researches respecting the improvement of the telescope. Having resolved, however, to complete his optical inquiries, he made them the subject of his lectures during the first three years of his appointment, and had thus ample opportunities, not only of repeating his former experiments, but of re-considering his doctrine of colours, and bringing it into a systematic form.

On the 23d December, 1671, the Lord Bishop of Sarum proposed Mr. Newton as a member of the Royal Society; and, on the 11th January, 1672, he was elected a Fellow of that learned body. At the same meeting, a telescope sent by Mr Newton from Cambridge, was exhibited to the Society, and it was agreed that the secretary should send a description of it to Mr. Huygens at Paris, for the purpose of securing for the inventor the honour which belonged to him. On the 25th January, Mr. Oldenburgh read to the Society a letter from Mr. Newton, concerning "an intimation of a considerable discovery he intends to send to the Society to be considered and examined." This discovery, which was laid before that body on the 8th February, was his new doctrine of the different refrangibility of the rays of light. It was received with peculiar commendation, and the society agreed to the immediate printing of it. in order to secure "the author against the *arrogations* of others." On the 9th December, 1675, another paper of Mr. Newton's was read, "containing partly an hypothesis to explain the properties of light, and partly the principal phenomena of the various colours exhibited by thin plates or bubbles, esteemed by him to be of a more difficult consideration, yet to depend also on the said properties of light." On the 16th December, when the remainder of this paper was read, "Mr Hook said that the main of it was contained in his Micrography, which Mr. Newton, in some particulars, had only carried further." In a few days Mr. Newton wrote a reply to this charge, which was read on the 20th January, 1676. "He stated the difference between his hypothesis and that of Mr. Hook, in his Micrography; the result of which is, that he (Mr. Newton) had nothing in common with Mr. Hook, but a supposition that ether is a medium susceptible of vibrations, of which supposition Mr Newton saith he makes quite a different use; Mr. Hook supposing it light itself, which Mr. Newton does not. Besides, that he explains very differently from Mr Hook, the manner of refraction and reflexion, and the nature and production of colours in all cases, and even in the colours of transparent substances. Mr. Newton says he explains every thing in a way so differing from Mr. Hook, that the experiments he grounds his discourse upon destroy all Mr. Hook saith about them. And that the two main experiments, without which the manner of production of those colours is not to be found out, were not only unknown to Mr. Hook, when he wrote his Micrography, but even last spring, as he understood, by mentioning them to the said Mr. Hook" Immediately after the letter which contained these sharp observations on Mr. Hook's unfounded claims, there was read another paper by Mr. Newton, containing his "Theory of the Colours of Natural Bodies," which pleased the company so well, that they were anxious to have it published. Sir Isaac, however, expressed his wish that the publication of his Observations upon Colours should be suspended for a while, as he intended to complete them by some additional experiments and observations.

Mr. Newton's first discoveries respecting the Colours of Light, which appeared in the Philosophical Transactions for 1671, did not experience that reception to which they were entitled. Father Pardies published two attacks upon the new doctrines; but, after two replies from Mr. Newton, the Cartesian philosopher abandoned the field. An anonymous Frenchman, M. N. revived the controversy in 1673, and when two papers had appeared on each side, the discussion was dropped. Father Lucas, and his pupil M. Gascoigne, followed in the same route of ignorant opposition to incontrovertible facts. M. Lucas of Liege opposed the theory even after repeating the experiments; but Newton, who replied to every animadversion that was made upon his opinions, finally triumphed over all his enemies, and left his Doctrine of Light and Colour as an imperishable monument of his industry and genius.

But though our author had the high satisfaction not only of knowing the soundness of his doctrines, but of seeing them universally received by those who could understand them, it was mingled with feelings of no very agreeable kind. The mean jealousies, both private and national, which had shown themselves during a controversy of four years continuance, made a deep impression on his candid and upright mind. He had no doubt imagined, under the influence of his own noble zeal for science, that new truths would meet with a welcome reception from all who bore the name of philosophers; and his surprise was great indeed when he made the only one of his discoveries which was truly mortifying to him, that the petty jealousies of vulgar life had often a deep root in minds which education and knowledge ought to have elevated and ennobled. So deep indeed was his mortification, that, in his preface to his Optics, he says, that in order "to avoid being engaged in disputes about these matters, I have hitherto delayed the printing, and should still have delayed it, had not the importunity of friends prevailed on me." He seems indeed to regret that he took any part in the controversy, when he says, "I blamed my own imprudence for parting with so real a blessing as my quiet, to run after a shadow."

In the winter of 1676 and 1677, he discovered the celebrated proposition, that by a centripetal force, varying in the inverse ratio of the distance, a planet will describe an ellipse about the centre of force placed in the lower focus, and that the radius vector will describe areas proportioned to the lines.

In the year 1680, Mr Newton made numerous observations on the comet, and, contrary to the opinion of Mr. Flamstead, he supposed that there were two different comets. Upon receiving a letter from Mr. Hook, explaining the nature of the line described by a falling body, supposed to be moved circularly by the diurnal motion of the earth, and perpendicularly by the power of gravity, he was led to inquire into the real orbit of such a body. In the course of the inquiry, he resumed his former speculations respecting the moon; and as Picard had, in 1679, measured a degree of the earth with considerable accuracy, he proceeded upon better data, and found that the moon was actually retained in her orbit by the power of gravity, and that this power decreased in the duplicate ratio of the distance. Hence he found that the line described by a falling body was an ellipse, having one of its foci in the earth's centre. In this manner was Newton led to the consideration of the planetary motions; and when Dr. Halley was at Cambridge about the end of 1684, he showed him a treatise *De Motu Corporum*, which he promised to send to the Royal Society to be entered in their register Dr. Halley mentioned these particulars to the Royal Society at their meeting on the 18th December, 1689, and he was desired, along with Mr. Paget, to put Mr. Newton in mind of his promise. In a letter dated the 25th of February, Mr. Newton signified his willingness to enter in their register his opinions about motion; and he seems to have spent the remainder of that year, and the whole of 1685, in arranging his various discoveries respecting the law of gravity and the planetary motions. On the 18th of April, 1686, he accordingly presented to the Royal Society, through Dr. Vincent, a manuscript treatise, entitled, *Philosophiæ Naturalis Principia Mathematica*, dedicated to the Society, in which, as the minute states, "he gives a mathematical demonstration of the Copernican hypothesis, as proposed by Kepler, and makes out all the phenomena of the celestial motions by the only supposition of a gravitation towards the centre of the sun, decreasing as the square of the distance therefrom reciprocally." On the 19th May, it was ordered "that Mr. Newton's book be printed forthwith in a 4to. of a fair letter; and that a letter be written to him to signify the Society's resolution, and to desire his opinion as to the print, volume, cuts, &c." On the 2d June, it was again ordered "that Mr. Edmund Halley shall undertake the business of looking after it, and printing it at his own charge, which he engaged to do."

This great work accordingly appeared under the abovementioned title about midsummer, 1687; but it did not at first receive that applause which it so well merited. From the universal prevalence of the Cartesian philosophy, on the one hand, and the mathematical acquirements which were necessary to understand the profound inquiries which the Principia contained, it was introduced slowly into notice. The triumph, however, of the new philosophy was sure in proportion to the slowness of its march; and when its value became generally known, it acquired for its author a brilliancy of reputation which had never before fallen to the lot of man. "Does Mr. Newton eat, drink, or sleep, like other men?" said the Marquis de l'Hospital to the English who visited him: "I represent him to myself as a celestial genius, entirely disengaged from matter."

In the year 1687, king James II. sent a mandamus to the University of Cambridge, to admit father Francis, an ignorant Benedictine monk, to the degree of M. A. This unwarrantable encroachment on the privileges of the university was strenuously resisted by its leading members, and Mr. Newton was appointed one of the delegates to the high commission court, where the university maintained its rights with such resolution and steadiness, that the king found it advisable not to press the matter any farther. Mr. Newton was in 1688 chosen one of the representatives of the University, in the convention parliament, which he regularly attended till its dissolution.

Mr. Montague, then chancellor of the exchequer, and afterwards earl of Halifax, was one of the friends and admirers of Newton, and sought every opportunity of proving the extent and sincerity of his friendship.[*] An opportunity having accordingly presented itself in 1696, by the promotion of Mr. Overton, warden of the mint, to be one of the commissioners of customs, Mr. Montague prevailed upon the king to appoint Mr. Newton warden of the mint;[†] an office in which he was of great service during the recoinage which took place soon after his appointment. In 1699, he was promoted to the situation of master and worker of the mint, an office worth from twelve to fifteen hundred pounds a year, which he held during the rest of his life. His whole conduct in this important office gave the highest satisfaction, and he had an opportunity of showing his chemical knowledge in his table of Assays of foreign coins, printed at the end of Dr. Arbuthnot's tables of ancient coins, weights, and measures, published in 1727.

In the year 1701, Mr. Whiston was appointed his deputy as professor of mathematics at Cambridge, and from that time he received all the salary, though Mr. Newton did not resign the professorship till 1703. On the 21st February, 1699, he was elected first titular of the seventh place of Foreign Associate of the Academy of Sciences of Paris.

Upon the resignation of John Lord Somers, Mr. Newton was chosen president of the Royal Society on the 30th November, 1703; a situation which he held for 29 years, till the time of his death.

On the 16th February, 1709, Mr. Newton presented to the Royal Society his book of Optics, "part of which," as he himself says, "was written at the desire of some gentlemen of the Royal Society, in the year 1675, and read at their meetings, and the rest was added about 12 years after, (1687) to complete the theory, except the third book and the last proposition of the second, which were since put together out of scattered papers, * * * * *. If any other papers, writ on this subject, are got out of my hands, they are imperfect, and were perhaps written before I had tried all the experiments here set down, and fully satisfied myself about the laws of refractions and composition of colours. I have here published what I think proper to come abroad, wishing that it may not be translated into another language without my consent."

"In a letter written to M. Leibnitz, in the year 1679, and published by Dr. Wallis, I mentioned a method by which I had found some general theorems about squaring curvilinear figures, or comparing them with the conic sections, &c. And some years ago, I lent out a MS. containing such theorems, and having since met with some things copied out of it, I have on this occasion made it public." This great work underwent other two editions in English, one in 1717, and the other in 1721. With the approbation of the author, Dr. Samuel Clarke translated his Optics into Latin, and it was done so entirely to Newton's satisfaction, that he presented Dr. Clarke with the sum of £500 upon its publication in 1706.

It is impossible not to observe from the whole of our author's conduct respecting his optical discoveries, that he valued them even higher than any of his other labours. The eagerness with which he replied to every objection which was started against them, and the unceasing care with which he repeated and perfected them, independent of more direct evidence, mark the high estimation in which he held them. The labours of Copernicus, of Kepler, and of Hook, had, in some measure, mingled themselves with his astronomical discoveries, and the claim of Leibnitz and the antecedent discoveries of Cavalerius and Fermat had marked the method of fluxions as a sort of common property, of which Newton was the superior,[‡] but his optical discoveries belonged to himself alone. No other eye had witnessed the splendid facts which he had observed and studied, and no other judgment had attempted to analyze that compound substance which he could decompose into its gaudy elements, and which he could with as much facility recombine. His theory of the colours of natural bodies too was as new as it was ingenious, and though opposed by those who could not comprehend its beauty, and too profound to gain the applause of those who were disposed to admire it, it will nevertheless be ranked among the finest speculations in science, and among the highest efforts of the genius of its author.

Disposed, as we are, to consider the optical discoveries of Newton as the finest specimens of physical research, we are not blind to the singular oversight which was committed by their author, and which we are persuaded contributed, in no slight degree, to retard the progress of that branch of knowledge. Newton *took it for granted* that glass, and water, and all other substances, gave a prismatic spectrum of the same length, when the mean refractions of the prisms were equal. He had actually formed the spectrum with prisms of water and of flint glass, and yet he did not observe that the latter gave much more colour than the former. Nay, though he had used prisms of numerous substances, all of which differed extremely in their power of producing colour, or dispersing the rays of light, yet he never suspected that such a difference existed. The slightest attempt to measure the length of the spectra; the slightest accident might have led him to this discovery, and consummated all his wishes by the invention of the achromatic telescope. Trusting to his accuracy, few persons could have ventured to repeat experiments which he had been correcting and revising during the last fifty years of his life, and it was, therefore, only from accidental causes, that future philosophers discovered the different dispersive powers of different media which led to the construction of achromatic telescopes. In the year 1705, Queen Anne conferred upon Mr. Newton the honour of knighthood.

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[*] Mr. Montague was elected president of the Royal Society on the 30th November, 1695, and held that office for three years.

[†] We cannot resist laying Mr. Montague's letter to Mr. Newton before our readers. It may be an useful model for future statesmen, though we belive it has been seldom imitated during the last century. This act of the Earl of Halifax will be remembered by posterity when the political events of his master's reign are forgotten.

"Sir,—I am very glad that at last I can give you a good proof of my friendship and of the esteem the king has of your merits. Mr. Overton, the warden of the mint, is made one of the commissioners of the customs, and the king has promised me to make Mr. Newton warden of the mint. The office is the most proper for you; 'tis the chief office in the mint; 'tis worth five or six hundreds per annum, and has not too much business to require more attendance than you may spare. I desire that you will come up as soon as you can, and will take care of your warrant in the mean time. Let me see you as soon as you come to town, that I may carry you to kiss the king's hand. I believe you may have a lodging near me. I am, &c.

Charles Montague.

[‡] Both Legrange and Laplace maintain that Fermat was the inventor of the method of fluxions. See our Article on Mathematics, where this strange opinion is considered at length.

The dispute between Newton and Leibnitz now commenced; but as we have already, in our Article FLUXIONS, and in our History of MATHEMATICS, entered very fully into the subject, we shall dismiss it entirely from this sketch of his life.

As this celebrated controversy excited very general attention, it was of course well known to the Elector of Hanover, at whose court Leibnitz filled the situation of Privy Councillor of Justice. Upon the accession of the Elector to the British throne as George I., Sir Isaac came under the particular notice of the court. Caroline, Princess of Wales, afterwards the queen consort of George II., who was fond of philosophical pursuits, and took much pleasure in the conversation of literary men, showed Sir Isaac particular marks of her favour. She often conversed with him for hours together, and was often heard to say in public, that she was happy at having lived in the same country, and at the same time with such an amiable and illustrious man. At her express desire, Sir Isaac drew up an abstract of his "Chronology," a MS. copy of which she requested him to give, under the promise of secrecy, (about 1718,) to Signior Conti, a Venetian nobleman, who was then in England. This nobleman, whose misconduct has given him immortality, betrayed in the basest manner the confidence that had been so generously reposed in him. As soon as he arrived in Paris, he got the MS. translated by a French antiquarian, who appended to it a series of observations, the object of which was to refute the original work. Sir Isaac was entirely ignorant of this base transaction till the 11th November, 1725, when he received, as a present, a small printed tract, from M. W. Cavelier, junior, a Parisian bookseller, entitled, *Abregé de Chronologié de M. le Chevalier Newton, fait par lui-même, et traduit sur le MSS. Anglois.* An advertisement was prefixed to the work, stating that three letters had been written to Sir Isaac, to ask his consent to the publication, and that his silence was at last taken for consent. In the mean time, Sir Isaac, who had never seen such letters, did return a written answer, (to an application from a friend,) in which he declined giving his consent; but the work had been printed, and the dishonest bookseller, though he received the letter before publication, did not hesitate to give it to the world. Sir Isaac, in a very interesting paper on this subject, published in the *Philosophical Transactions*, 1725, vol. xxxiii. p. 315, exposes the nature of the deceitful transaction, and repels, in a masterly manner, the objections which had been made to his system. The following paragraph, which concludes this paper, is too much connected with the history of his life not to be interesting to every reader, and the more so when we consider that it was composed in his 83d year.

"The Observator," says he, "represents that I have a great work to come out; but I never told him so. When I lived at Cambridge, I used sometimes to refresh myself with history and chronology for a while, when I was weary with other studies: but I never told him that I was preparing a work of that kind for the press.

"Abbé Conti came into England in spring 1715, and while he staid in England, he pretended to be my friend, but assisted M. Leibnitz in engaging me in new disputes, and has since acted in the same manner in France. The part he acted here may be understood by the character given of him in the *Acta Eruditorum*, for the year 1721, p. 90, where the editor, excusing himself for repeating some disputes which had been published in these *Acta*, subjoins, 'Let it therefore suffice to say, that when the Abbé Conti, a noble Venetian, (of whom M. Leibnitz acknowledges M. Herman gave a good character,) came over from France into England, he undertook to be mediator in the disputes between Sir I. Newton and M. Leibnitz; and took the care of transmitting their letters to each other,' and how M. Leibnitz, by this mediation, endeavoured to engage me, against my will, in their disputes about occult qualities, universal gravity, the sensorium of God, space, time, vacuum, atoms, the perfection of the world, supramundane intelligence, and mathematical problems, is mentioned in the preface to the second edition of the *Commercium Epistolicum*. And what he has been doing in Italy, may be understood by the disputes raised there by one of his friends who denies many of my optical experiments, though they have been all tried in France with success."

This answer of Sir Isaac's,* induced P. Souciet, who, it appears, was the antiquary alluded to, to write five additional dissertations against the new system of chronology, but as these were published about the time of Sir Isaac's death, it fell to the lot of Dr. Halley to reply to him, which he did in the *Philosophical Transactions* for 1727, vol. xxxiv. and xxxv. p. 205, 296.

In the year 1722, Sir Isaac, who had in general enjoyed good health, was afflicted with an incontinence of urine, which was supposed to proceed from stone in the bladder, and which his medical attendants thought incurable. By great care, however, and a strict attention to regimen, living chiefly on broth, vegetables, and fruit, he subdued, to a certain degree, this dreadful malady, and enjoyed considerable intervals of ease during the rest of his life.

In January, 1725, he was persuaded to take a house at Kensington, in consequence of a violent cough and inflammation in his lungs; and, in 1726, he had a fit of the gout for the second time. In the winter of 1721, he wished to resign his situation in the mint to Mr. Conduit, who had married his niece (the witty Miss Barton,) but Mr. Conduit would not permit the resignation to take place; and, for about a year before Sir Isaac's death, he performed for him the whole duties of his office.

On Tuesday, the last day of February 1727, Sir Isaac went to town to attend a meeting of the Royal Society. Mr. Conduit found him next day in better health than he had enjoyed for several years; but the fatigue of attending the society, and of paying and receiving visits, occasioned a return of his former disease. Dr. Mead and Mr. Chesselden, who went to see him at Kensington, pronounced it to be the stone.

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* The Abbé Conti wrote a reply in 1726, which we have not seen.

During the severe paroxysms, which not unfrequently supervened, the drops of sweat often ran down his face without extorting the slightest complaint or expression of impatience, and when the agony had passed, he would again converse with his usual cheerfulness and serenity.

On Wednesday, the 15th of March, he was considerably relieved, and some hopes of his recovery were cherished by his friends. Their expectations, however, were fallacious. On the 18th March he read the newspapers; and in a long conversation with Dr. Mead, he showed that he had the possession of all his faculties. On the same evening, however, after six o'clock, and during the whole of Sunday, he was insensible, and died on Monday, March 20th, between one and two o'clock in the morning, having reached the great age of 84 years and a few months.

His personal estate, to the amount of 32,000*l.* was divided among his five nephews and nieces of half blood. The land, which he inherited, descended to John Newton, whose great-grandfather was Sir Isaac's uncle. Previous to his death he had given away an estate in Berkshire to the sons and daughters of Mrs. Conduit's brother, and an estate in Kensington to Mrs. Conduit's daughter, who was afterwards married to the eldest son of Lord Lymington, from whom the present Earl of Portsmouth is descended.

The corpse of this great man lay in state in the Jerusalem Chamber, adjoining the House of Lords; and on the 28th March, it was conveyed from thence to Westminster Abbey, near the entrance to the choir, where it was buried with great magnificence, and at the public expense. This sacred spot is one of the most conspicuous in the abbey, and had been refused to different noblemen who had asked it. The pall was supported by the Lord High Chancellor, the Dukes of Montrose and Roxburgh, and the Earls of Pembroke, Sussex, and Macclesfield. The honourable Sir Michael Newton, Knight of the Bath, was the chief mourner, and was accompanied by the relations and several distinguished friends of Sir Isaac's. Dr. Bradford, Bishop of Rochester, attended by the prebend and choir, performed the funeral service. A splendid monument, with the following inscription, was erected to his memory at the public expense.

H. S. E.
ISAACUS NEWTON, EQUES AURATUS,
QUI ANIMI VI PROPE DIVINA,
PLANETARUM MOTUS, FIGURAS,
COMETARUM SEMITAS OCEANIQUE ÆSTUS,
SUA MATHESI FACEM PREFERENTE,
PRIMUS DEMONSTRAVIT.
RADIORUM LUCIS DISSIMILITUDINES,
COLORUMQUE INDE NASCENTIUM PROPRIETATES,
QUAS NEMO ANTEA VEL SUSPICATUS ERIT, PERVESTIGAVIT.
NATURÆ ANTIQUITATIS. S. SCRIPTURÆ,
SEDULUS SAGAX. FIDUS INTERPRES,
DEI. OPT. MAX. MAJESTATEM PHILOSOPHIA ASSERUIT,
EVANGELII SIMPLICITATEM MORIBUS EXPRESSIT.
SIBI GRATULENTUR MORTALES, TALE TANTUMQUE EXTITISSE,
HUMANI GENERIS DECUS
NATUS XXV. DECEMB. MDCXLII, OBIIT XX MART.
MDCCXXVII.

By the munificence of Dr. Smith, Master of Trinity College, Cambridge, an admirable full length statue of Sir Isaac, by Roubilliac, was placed in the outer chapel in that college, but has since been removed to the senate house. A medal was struck to his memory by Croker of the English mint, another by Dassier of Geneva, and a third by Roettiers in France. The only portrait of him, for which he sat, was by Kneller, and is said to be in the collection of the Duke of Rutland.

Sir Isaac Newton was of the middle size, and in the latter part of his life was rather plump. To the time of his last illness, he had the bloom and the colour of youth, and a forehead of hair as white as silver, and without any baldnesss. He never required spectacles, and lost only one tooth during his long life. Fontenelle remarks that he had a lively and piercing eye, but Bishop Atterbury denies that this was the case during the 20 years that he knew him. "Indeed, in the whole air of his face and make, there was nothing of that penetrating sagacity which appears in his compositions. He had something rather languid in his look and manners, which did not raise any great expectations in those who did not know him."*

There was no feature in the character of this great man more remarkable than the equanimity of his temper, and his sincere love of peace. The disputes in which he was involved by the jealousies and unfounded pretensions of others, broke in upon that serenity of mind which it was his great object to maintain. But though he had an instinctive horror at that species of controversy where the feelings of the combatants are engaged along with their judgments, he did not shrink from the duty of self-defence, and he accordingly replied to his antagonists with a spirit and firmness which diminished their number and silenced their opposition. His observations on the Abbé Conti and on Leibnitz, which we have already quoted, and which were written in his 83d year, prove how keenly he felt the injustice of their treatment, and how little he scrupled to express the feelings which it had excited. To have submitted, indeed, to the criticisms and claims of his enemies, would have been to acquiesce in their justness, and he had formed too great an estimate of the duties and exertions of his scientific career, to surrender, without a struggle, those discoveries and improvements which had been the principal business of his life.

Sir Isaac Newton was particularly distinguished from almost all other great men, by his humility and unpretending modesty. Instead of arrogating to himself a superiority over others, he was always found on the same level with those with whom he associated. He had no singularities either in his conduct or in his opinions. He attributed his discoveries solely to the industry and patience with which he interrogated nature; and every step which he made, either in acquiring knowledge or in advancing its boundaries, seems only to have created a new degree of humility, and to have shown him how little he really knew, and what a small portion he had discovered of what yet remained to be known.

In his religious character, Sir Isaac was not less worthy of admiration. That he was a Christian, in the most extensive sense of the word, has never been doubted but by those who wished him to have been an infidel. In the latter part of his life, in particular, he devoted a great portion of his time to the study of the Scriptures;

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* Atterbury's *Correspondence*, vol. ii. p. 327.

and though he was firmly attached to the church of England, he maintained the necessity of universal toleration. The sincerity of his piety was evinced by a life of liberality and virtue; and there is nothing more remarkable in the history of this great man than the perfect symmetry of his moral, his religious, and his philosophical character.

The following list of Newton's Works and Papers is taken from Hutton's *Mathematical Dictionary*, and cannot fail to be interesting to the reader:

1. Several papers relating to his *Telescope*, and his *Theory of Light and Colours*, printed in the Philosophical Transactions, Nos. 80, 81, 82, 83, 84, 85, 88, 96, 97, 110, 121, 123, 128; or vols. 6, 7, 8, 9, 10, 11.

2. *Optics*, or a *Treatise of the Reflections, Refractions, and Inflections, and the Colours of Light*, 1704, 4to.—A Latin translation by Dr. Clarke; 1706, 4to.—And a French translation by Pet. Coste, Amst. 1729, 2 vols. 12mo.—beside several English editions in 8vo.

3. *Optical Lectures*; 1728, 8vo. Also in several letters to Mr. Oldenburgh, Secretary of the Royal Society, inserted in the General Dictionary, under the article Newton.

4. *Lectiones Opticæ*; 1729, 4to.

5. *Naturalis Philosophiæ Principia Mathematica*; 1687, 4to.—A second edition in 1713, with a Preface by Roger Cotes.—The 3d edition in 1726, under the direction of Dr. Pemberton.—An English translation, by Motte, 1729, 2 vols. 8vo. printed in several editions of his works, in different nations, particularly an edition, with a large Commentary, by the two learned Jesuits, Le Seur and Jacquier, in 4 vols. 4to. in 1739, 1740, and 1742.

6. *A System of the World*, translated from the Latin original; 1727, 8vo.—This, as has been already observed, was at first intended to make the third book of his Principia.—An English translation, by Motte, 1729, 8vo.

7. *Several Letters* to Mr. Flamstead, Dr. Halley, and M. Oldenburg.—See our author's article in the General Dictionary.

8. *A Paper concerning the Longitude*; drawn up by order of the House of Commons, ibid.

9. *Abregé de Chronologie*, &c. 1726, under the direction of the Abbé Conti, together with some Observations upon it.

10. *Remarks upon the Observations made upon a Chronological Index of Sir I. Newton*, &c. Philos. Trans. vol. 33. See also the same, vol. 34 and 35, by Dr. Halley.

11. *The Chronology of Ancient Kingdoms amended*, &c. 1728, 4to.

12. *Arithmetica Universalis*, &c.; under the inspection of Mr. Whiston, Cantab. 1707, 8vo. Printed, it is said, without the author's consent, and even against his will: an offence which it seems was never forgiven. There are also English editions of the same, particularly one by Wilder, with a Commentary, in 1767, 2 vols. 8vo. And a Latin edition, with a Commentary, by Castilion, 2 vols. 4to. Amst. &c.

13. *Analysis per Quantitatum Series, Fluxiones et Differentias, cum Enumeratione Linearum Tertii Ordinis*; 1711, 4to.; under the inspection of W. Jones, Esq. F. R. S.—The last tract had been published before, together with another on the *Quadrature of Curves*, by the method of Fluxions, under the title of *Tractatus duo de Speciebus et Magnitudine Figurarum Curvilinearum*; subjoined to the first edition of his Optics, in 1704; and other letters in the Appendix to Dr. Gregory's Catoptrics, &c. 1735, 8vo.—Under this head may be ranked, *Newtoni Genesis Curvarum per Umbras*; Leyden, 1740.

14. *Several Letters relating to his Dispute with Leibnitz*, upon his right to the Invention of Fluxions; printed in the *Commercium Epistolicum D. Johannis Collins & aliorum de Analysi Promota jussu Societatis Regiæ editum*; 1712, 8vo.

15. Postscript and Letter of M. Leibnitz to the Abbé Conti, with Remarks, and a Letter of his own to that Abbé; 1717, 8vo. To which was added, Raphson's History of Fluxions, as a Supplement.

16. *The Method of Fluxions, and Analysis, by Infinite Series*, translated into English from the original Latin; to which is added, a Perpetual Commentary, by the translator Mr. John Colson; 1736, 4to.

17. *Several Miscellaneous Pieces, and Letters*, as follow:—(1.) A Letter to Mr. Boyle upon the subject of the Philosopher's Stone. Inserted in the General Dictionary, under the article Boyle.—(2.) A Letter to Mr. Aston, containing directions for his travels; ibid. under the article Newton.—(3.) An English Translation of a Latin Dissertation upon the Sacred Cubit of the Jews. Inserted among the miscellaneous works of Mr. John Greaves, vol. 2d, published by Dr. Thomas Birch, in 1737, 2 vols. 8vo. This Dissertation was found subjoined to a work of Sir Isaac's, not finished, entitled *Lexicon Propheticum*.—(4.) Four Letters from Sir Isaac Newton to Dr. Bentley, containing some arguments in proof of a Deity; 1756, 8vo.—(5.) Two Letters to Mr. Clarke, &c.

18. *Observations on the Prophecies of Daniel and the Apocalypse of St. John*; 1373, 4to.

19. *Is. Newtoni Elementa Perspectivæ Universalis* 1746, 8vo.

20. *Tables for Purchasing College Leases*; 1742, 12mo

21. Corollaries, by Whiston.

22. A Collection of several pieces of our author's, under the following title, *Newtoni Is. Opuscula Mathematica Philos. & Philol.* collegit J. Castiloneus; Laus. 1744, 4to. 8 tomes.

23. *Two Treatises* of the Quadrature of Curves, and Analysis by Equations of an Infinite Number of Terms, explained: translated by John Stewart, with a large Commentary; 1745, 4to.

24. *Description of an Instrument* for observing the Moon's Distance from the Fixed Stars at Sea. Philos. Trans. vol. xlii.

25. Newton also published *Barrow's Optical Lectures*, in 1699, 4to.; and *Bern. Varenii Geographia, &c.*; 1681, 8vo.

26. The whole works of Newton, published by Dr. Horsley; 1779, 4to. in 5 volumes.

The following is a list of the Papers left by Newton at his death, as mentioned above:

A Catalogue of Sir Isaac Newton's Manuscripts and Papers, as annexed to a Bond, given by Mr. Conduit, to the Administrators of Sir Isaac; by which he obliges himself to account for any profit he shall make by publishing any of the Papers.

Dr. Pellet, by agreement of the executors, entered into Acts of the Prerogative Court, being appointed to peruse all the papers, and judge which were proper for the press.

No.
1. Viaticum Nautarum; by Robert Wright.
2. Miscellanea; not in Sir Isaac's hand writing.
3. Miscellanea; part in Sir Isaac's hand.
4. Trigonometria; about 5 sheets.
5. Definitions.
6. Miscellanea; part in Sir Isaac's hand.
7. 40 sheets in 4to. relating to Church History.
8. 126 sheets written on one side, being foul draughts of the Prophetic Stile.
9. 88 sheets relating to Church History.
10. About 70 loose sheets in small 4to. of Chemical papers; some of which are not in Sir Isaac's hand.
11. About 62 ditto, in folio.
12. About 15 large sheets, doubled into 4to; Chemical.
13. About 8 sheets ditto, written on one side.
14. About 5 sheets of foul papers, relating to Chemistry.
15. 12 half-sheets of ditto.
16. 104 half-sheets, in 4to. ditto.
17. About 22 sheets in 4to. ditto.
18. 24 sheets, in 4to. upon the Prophecies.
19. 29 half-sheets; being an answer to Mr. Hook, on Sir Isaac's Theory of Colours.
20. 87 half-sheets relating to the Optics, some of which are not in Sir Isaac's hand.

From No. 1. to No. 20, examined on the 20th of May, 1727, and judged not fit to be printed.

T. Pellet.
Witness, Tho. Pilkington.

21. 328 half-sheets in folio, and 63 in small 4to; being loose and foul papers relating to the Revelations and Prophecies.
22. 8 half-sheets in small 4to, relating to Church Matters.
23. 24 half-sheets in small 4to.; being a discourse relating to the 2d of Kings.
24. 353 half-sheets in folio, and 57 in small 4to.; being foul and loose papers relating to Figures and Mathematics.
25. 201 half-sheets in folio, and 21 in small 4to.; loose and foul papers relating to the Commercium Epistolicum.
26. 91 half-sheets in small 4to, in Latin, upon the Temple of Solomon.
27. 37 half-sheets in folio, upon the Host of Heaven, the Sanctuary, and other Church Matters.
28. 44 half-sheets in folio, upon Ditto.
29. 25 half-sheets in folio; being a farther account of the Host of Heaven.
30. 51 half-sheets in folio; being an Historical Account of two notable Corruptions of Scripture.
31. 88 half-sheets in small 4to; being Extracts of Church History.
32. 116 half-sheets in folio; being Paradoxical Questions concerning Athanasius, of which several leaves in the beginning are very much damaged.
33. 56 half-sheets in folio, De Motu Corporum; the greatest part not in Sir Isaac's hand.
34. 61 half-sheets in small 4to; being various sections on the Apocalypse.
35. 25 half-sheets in folio, of the Working of the Mystery of Iniquity.
36. 20 half-sheets in folio, of the Theology of the Heathens.
37. 24 half-sheets in folio; being an Account of the Contest between the Host of Heaven and the Transgressors of the Covenant.
38. 31 half-sheets in folio; being Paradoxical Questions concerning Athanasius.
39. 107 quarter-sheets in small 4to, upon the Revelations.
40. 174 half-sheets in folio; being loose papers relating to Church History.

May 22, 1727, examined from No. 21. to No. 40, inclusive, and judged them not fit to be printed: only No. 33. and 38. should be reconsidered.

T. Pellet.
Witness, Tho. Pilkington.

41. 167 half-sheets in folio; being loose and foul papers relating to the Commercium Epistolicum.
42. 21 half-sheets in folio; being the 3d letter upon Texts of Scripture, very much damaged
43. 31 half-sheets in folio; being foul papers relating to Church Matters.
44. 495 half-sheets in folio; being loose and foul papers relating to Calculations and Mathematics.
45. 335 half-sheets in folio; being loose and foul papers relating to the Chronology.
46. 112 sheets in small 4to, relating to the Revelations and other Church Matters.
47. 126 half-sheets in folio; being loose papers relating to the Chronology, part in English and part in Latin.
48. 400 half-sheets in folio; being loose Mathematical papers.
49. 109 sheets in 4to, relating to the Prophecies and Church Matters.
50. 127 half-sheets in folio, relating to the University; great part not in Sir Isaac's hand.
51. 18 sheets in 4to; being Chemical papers.
52. 255 quarter-sheets; being Chemical papers.
53. An Account of Corruptions of Scripture; not in Sir Isaac's hand.
54. 31 quarter-sheets; being Flammel's Explication of Hieroglyphical Figures.
55. About 350 half-sheets; being Miscellaneous papers.
56. 6 half-sheets; being An Account of the Empires, &c. represented by St. John.
57. 9 half-sheets folio, and 71 quarter-sheets 4to; being Mathematical papers.
58. 140 half-sheets, in 9 chapters, and 2 pieces in folio, titled, Concerning the Language of the Prophets.
59. 606 half-sheets folio, relating to the Chronology; 9 more in Latin.
60. 182 half-sheets folio. being loose papers relating to the Chronology and Prophecies.
61. 144 quarter-sheets, and 95 half-sheets folio; being loose Mathematical papers.
62. 137 half-sheets folio; being loose papers relating to the dispute with Leibnitz.
63. A folio Common-place book; part in Sir Isaac's hand.
64. A bundle of English letters to Sir Isaac, relating to Mathematics.
65. 54 half-sheets; being loose papers found in the Principia
66. A bundle of loose Mathematical Papers; not Sir Isaac's.

67. A bundle of French and Latin Letters to Sir Isaac.
68. 136 sheets folio, relating to Optics.
69. 22 half-sheets folio, De Rationibus Motuum, &c.; not in Sir Isaac's hand.
70. 70 half-sheets folio; being loose Mathematical Papers.
71. 38 half-sheets folio; being loose papers relating to Optics.
72. 47 half-sheets folio; being loose papers relating to Chronology and Prophecies.
73. 40 half-sheets folio; Procestus Mysterii Magni Philosophicus, by Wm. Yworth; not in Sir Isaac's hand.
74. 5 half sheets; being a letter from Rizzetto to Martine, in Sir Isaac's hand.
75. 41 half-sheets; being loose papers of several kinds, part in Sir Isaac's hand.
76. 40 half-sheets; being loose papers, foul and dirty, relating to Calculations.
77. 90 half-sheets folio; being loose Mathematical papers.
78. 176 half-sheets folio; being loose papers relating to Chronology.
79. 176 half-sheets folio; being loose papers relating to the Prophecies.
80. { 12 half-sheets folio; An Abstract of the Chronology.
    92 half-sheets folio; The Chronology. }
81. 40 half-sheets folio; The History of the Prophecies, in 10 chapters, and part of the 11th unfinished.
82. 5 small bound books in 12mo, the greatest part not in Sir Isaac's hand, being rough Calculations.

May 26th, 1727, Examined from No. 41. to No. 82, inclusive, and judged not fit to be printed, except No. 80, which is agreed to be printed, and part of No. 61 and 81, which are to be reconsidered.

Th. Pellet.
Witness, Tho. Pilkington.

It is astonishing what care and industry Sir Isaac had employed about the papers relating to Chronology, Church History, &c.; as, on examining the papers themselves, which are in the possession of the family of the Earl of Portsmouth, it appears that many of them are copies over and over again, often with little or no variation; the whole number being upwards of 4000 sheets in folio, or 8 reams of folio paper; beside the bound books, &c. in this catalogue, of which the number of sheets is not mentioned. Of these there have been published only the Chronology, and Observations on the Prophecies of Daniel and the Apocalypse of St. John."

For an account of Sir Isaac Newton's discoveries, the reader is referred to the articles Astronomy, Geometry, Fluxions, Mathematics, and Optics. For more minute details respecting some parts of his life, see his Elogé by Fontenelle in the *Mem. Acad. Par.* 1727, Hist. p. 151; Turner's *Collections for the Town and Stoke of Grantham*, 1806, which contains the original life of Newton drawn up by Conduit, for the information of M. Fontenelle, and published from the MS. in the possession of the Earl of Portsmouth. Thomson's *History of the Royal Society*, p. 277., and App. No. III. See also the *Edinburgh Philosophical Journal*, vol. iii. p. 293, for some curious information respecting his family.

The following references to the *Gentleman's Magazine*, for interesting information respecting our author, were collected by our celebrated countryman, Dr. Robison, who had proposed to write a life of Newton, Vol. I. p. 27, 159, 202. Vol. II. 917. VII. 24, 674; X. 594. XV. 256. XXIV. 143, 219. XXV. 3, 31, 328. XXVIII. 263. XXX. 169. XLII. 207, 212, 520. XLIV. 531. XLVII. 71. XLVIII. 64. L. 321, 414. LI. 580 LII. 227, 329, 367, 575. LV. 779. LVI. 10, 96, 394.

NIAGARA, a river of North America, between lakes Erie and Ontario. It is, strictly speaking, a strait uniting the two lakes.

It commences by a rapid, two miles N. N. W. from the town of Buffalo. The rapid terminates at or a little below Black Rock, and assuming a placid current, with a width from half to one and a half mile wide, the river flows from Black Rock to the head of Grand Isle, seven miles, with a course nearly N. W. Here it divides into two large branches, which, encircling Grand Isle, again reunite three miles above the falls Now upwards of a mile wide, and gradually contracting in breadth, and increasing in velocity, the whole mass approaches the great ledge, which forms the tremendous cataract of Niagara.

This ledge is itself a part of the vast floetz strata, which stretches along the southern shores of lake Ontario, crosses Niagara river, and reaches to an unknown distance into Canada.

Below Grand Isle, the river turns to a course of nearly west, which it continues to the falls, where it abruptly curves to N. E, which it continues about a mile, from whence it assumes a northern direction, which with some partial bends it continues to lake Ontario. See the succeeding article, Niagara Falls.

NIAGARA Falls, is a cataract in Niagara river, formed by the intersection with that stream of the great ledge, noticed in the article Niagara river.

The following table exhibits the entire length of Niagara river, and the respective fall from Erie to Ontario.

	Miles.	Fall.
From lake Erie to the head of the rapids,	20	15 ft.
Do. rapids to the head of the fall, -	1½	51
Great fall, - - - -		162
From Falls to Lewistown, - -	7	104
From Lewistown to lake Ontario, -	7	2
Entire distance and fall, - -	35½	334

Standing on either side of Niagara river above the Falls, the aspect of the adjacent country is that of a general level. Nothing announces an approach to the cataract, except the spray and cloud of vapour, which rises from the surge below.

The water is precipitated over an immense mass of limestone rock, which forms the bed of the river. The width of the river in a straight line, at the falls, is three-fourths of a mile. But as its principal force is exerted in the centre, the brow of the precipice has been worn in the shape of a horse-shoe, and its whole winding width is not less than a mile and a half. This distance is divided by a small woody island, called Goat island, near the American side, which divides the cataract into two. The elevation of this island above the surface of the stream is not very great, but it presents towards the north-west a bold perpendicular front of bare solid rock, the whole height of the cataract. The width of the fall between Goat Island and the American side is about one-fifth of the whole, and that of the island itself another fifth; although the quantity of water on the British side is probably ten times as great as on the other. A bridge now connects the New York shore to Goat Island.

The Table Rock is a part of the Canada bank, which is on the margin of the great sheet of falling water. It furnishes altogether the most interesting view of the falls. The eye, looking up the river, beholds it tumbling with wild magnificence over the ledges of rocks, which, seen from this place, seem close together, and appear to constitute a single broken cataract. The immense mass of waters, greatly increased in its rapidity by this descent, and perhaps still more by the contraction of the river, rolls with an apparently instantaneous motion to to the brow of the precipice, and shoots over it into the abyss below. The depth of the precipice, the roar of the cataract, the mass of the waters, and, above all, the inconceivable exertion of power, overwhelm the mind with emotions of sublimity and grandeur; and fill it with new and clearer views of the weakness and littleness of man.

From the surface of the stream beneath, on the Canada side, there arises a thick and constant cloud of vapour, which mounts above the precipice to the height of more than 100 feet. In clear weather, three primary rainbows are frequently visible at once in various parts of this cloud. These, when the sun is near the horizon, appear complete semicircles, and are often of singular lustre and beauty. Beneath the fall lies a thick mass of foam, which, for a great extent, covers the surface of the water. The banks of the river below are on both sides perpendicular, of solid rock, and of the same height with those above the fall. They continue of this height seven miles to Queenstown. Here the cataract is supposed to have commenced after the deluge, and from this place to have worn its way backward to its present spot. No one who examines the ground will doubt for a moment that this has been the case; and those who have lived for 20 years on the bank all attest this retrograde motion. These falls are in Lat. 43° 05′ N.

A more minute account of these falls will be found in the *Phil. Trans.* 1722, vol. xxxii. p. 69; and in Volney's *Travels.*

DARBY.

NICE, NICÆA, NEXAIA, or NIZZA, (from Νικη, *victory*,) a city and sea-port town in the kingdom of Sardinia, is situated in a fine amphitheatre, of a triangular form. In approaching it from Antibes it is limited on the east by high mountains. To the north and west it is bounded by the river Paglione, and to the south it is washed by the sea. The town stands near the mouth of the river Paglione, and on the left bank of the Var. The streets are very narrow, and are rendered dark and gloomy by the height of the houses. The names given to them during the revolution were ill suited to their character. In the *Rue La Lumiere* it was scarcely possible to see at mid-day. The *Rue du Bonheur* was the dullest of all, and was inhabited by the most miserable of the citizens; and those of *Bonair* and *Propreté* were equally undeserving of their name. The stairs of the houses are built of a black schistus, from the coast of Genoa. Among those which are newly built at the sea side, there are some which have a tolerably good appearance, from their painted facades. The greater number of houses have a chimney only in the kitchen, so that in cold weather it is necessary to heat the apartments by a chauffer. The churches of Nice are in no way remarkable. That of *Sainte Reparata* is of very common architecture. On solemn occasions, the whole of the interior is covered with red damask adorned with gold lace. At the extremity of the old town is the gate which enters on the side of Piedmont, and also the Place Victor, which is surrounded, like the Place Royale at Paris, with regular houses built on arcades. The new part of the town, which is near the sea, has been built for about 54 years. The streets are fine, wide, and well laid out. Here are the Place Royale, for exercising the troops, and the *Cours*, which is planted with two rows of fine oak trees, which form an agreeable promenade during the day. The terrace is a very elevated platform, supported by a row of buildings, which serve as warehouses for merchants. This place is the evening promenade. The view from it is quite delightful. On the Mediterranean are seen the boats of the fishermen, and the ships sailing for Marseilles and Genoa; and in clear weather the mountains of Corsica may be distinctly perceived in the horizon. In descending towards the east of this fine terrace, we come to a road formed round the rock, the windings of which we follow as on a balcony. When the sea is tempestuous, their violent dashings against the rock produce a fine effect. This rampart, which is accessible for carriages, leads to the harbour. From the extremity of the mole we can distinguish the mountains on the coast of Genoa. The harbour is entirely artificial. The two moles, which protect the entrance to it, are well built with hewn stone; but the harbour itself is very small, and will scarcely contain 40 merchant ships. It would not be difficult, however, to enlarge it; and it has been proposed to extend it to the *Place Victor.* Near the harbour are vaults and niches, under which the sailors may find shelter and prepare their victuals; and an acqueduct brings water here from the distance of half a league. In the harbour there have been found nails of bronze, well preserved. One of them was between a bed of stone and clay. To the east, behind the harbour, stood the castle, which was once deemed impregnable. A bomb, however, lighted on the powder magazine in 1691, and blew up the donjon into the air. The church of St. Stephen is situated in the middle of a field, about half a league from the town. The square enclosure, before the entrance to the church, is surrounded with a high wall, and is paved in Mosaic, with black, brown, and white flints. It represents a Maltese cross, and several other ornaments, in the middle of which is the date 1724. At Cimiez or *Cimea*, anciently *Cemenalium*, about two miles from this, are the remains of an amphitheatre, temple, aqueduct, and baths. The amphitheatre is 132 feet long, and 112 wide. The arena, which is of an oval form, is well preserved, and the upper steps enjoyed a view of the sea. It might have contained a thousand spectators. The arena is now sown with corn and planted with olive trees. The convent of the ancient Recollets, and the church called Notre Dame de Cimiez, contain some interesting objects. Among the other objects of interest at Nice, are the ruins of a temple at Ferreti, the harbour of Ville Franche, about half a league from Nice, capable of containing a hundred ships of the line; the lighthouse; and the Fort of Montalban. Some of the finest points of view are before the house of Cesoli, and at the country house of Chais. The Chemin du

Var is a favourite promenade, both on account of the fine points of view which it affords, and on account of the fine walks in the forest along the banks of the Var, about a league from Nice. There are at Nice a theatre, a library, public baths, and coffee-houses. The exports from Nice are chiefly oil, wine, of which a good deal is sold in England as Burgundy, silk, liqueurs, essences, and perfumery; and bulbous rooted flowers, sent in winter by post to Paris, in moss, where they generally arrive quite fresh. Its manufactures are those of silk, leather, paper, soap, and tobacco. Nice enjoys a very uniform and delightful temperature, from its sheltered situation. The heat of summer would be overpowering were it not for the sea breeze. The winter is nearly as warm as the month of May in England, and hence it is a favourite place of resort for consumptive invalids. Population 18,473. East Long. 7° 16′ 35″, North Lat. 43° 41′ 16″. For a particular account of Nice, see *Voyage Historique et Pittoresque du Comté de Nice*, par M. Albane Beaumont. A Geneve, 1787. *Voyage dans le departement des Alpe Maritimes, avec la Description de la Ville et de terroir de Nice, &c.* par Papon. Paris 1804; and Millin's *Voyage dans les departemens du Midi de la France*, tom. ii. chap. lxvi. lxvii. p. 520.

NICOBAR Islands are situated in the south-east quarter of the Bay of Bengal, between the 6th and 10th degrees of North latitude, or nearly in the 94th degree of East longitude, stretching north-west from Sumatra to the most southerly of the Andaman isles. Many of them are very small, and without any distinct appellation; but twelve of them, at least, are of a moderate extent, of which the names are Nicobar, Carnicobar, Quoin, Chowry, Teressa, Tillanjang, Nancowry or Nuncovery, Comarty or Cæmarta, Tricut, Katshall or Catchowl, Sambelong, and Taruss or Tavass. Sambelong, towards the south, is the largest; but Carnicobar, the most northerly, and Nancowry, nearly in the centre of the group, are most visited by Europeans. The last mentioned, which is about eight miles in length, and as much in breadth, together with Comarty, which is rather larger, and Tricut, a small flat island, are so situated as to form in the space between them one of the most capacious and sheltered harbours in the Indian seas. Most of those islands are hilly, and some of the mountains are of a considerable elevation. They are in general also covered with wood; and from the summits of the hills the prospects are frequently beautiful and romantic.

The climate of these islands is not oppressively hot, and the shores are visited by refreshing sea-breezes; but the extent and thickness of the woods prevent the free circulation of air amidst their decaying fruits and leaves; and they are all most unhealthy spots to an European constitution. The soil, naturally fertile, is almost entirely uncultivated; but the greater part of the most valuable productions of tropical climates grow up spontaneously in the highest perfection. The forests are full of large and lofty trees, many of which are capable of furnishing excellent timber, some of them 34 feet in circumference. So luxuriant is their growth, that the light of the sun cannot penetrate through their foliage, and it is almost perfectly dark in the woods. The trees are also in many places so closely interwoven with immense quantities of rattan and bush ropes, that they appear in a manner spun together, and are utterly impervious to the inhabitants. The most abundant of these trees, and the most valued by the natives, are the cocoa and areca palms; the former of which thrives best on the sea-coast, where its roots and stem are reached by the flood-tides. Plantains, limes, tamarinds, beetle-nuts, the larum, or mellory, (a species of bread-fruit,) cinnamon, sassafras, and the coffee-tree, are among the most common productions. The wholesome and delicious mango, and pine apples of the finest flavour, grow wild in the woods. Yams, sweet potatoes, and a variety of other useful roots and vegetables, are raised every where without trouble or care.

There are no beasts of prey in the Nicobars, such as tigers, leopards, &c.; but monkeys of different species are found in the southernmost islands; and dogs and swine abound in them all. In some of them are large herds of buffaloes and of other cattle, which were originally introduced by the Danes, and have run wild in the woods since their colony was abandoned. These animals have increased rapidly; and as the upper regions of the mountains are covered with fine grass, many of the buffaloes, particularly, have grown to a great size. There are also numbers of large rats in most of the islands. There is no great variety of birds in those islands. Pheasants, turtle-doves, wild pigeons, and particularly parrots, are numerous. The bats are of an immense size and hideous aspect. Some of them have bodies as large as that of a cat, and measure from five to six feet across the back between the extreme points of their extended wings. There are two kinds of them, one of which has a head like that of a dog, and the other like that of a cat; the former making a barking, and the latter a mewing noise, while on the wing. But the most remarkable of the birds, is the Nicobar swallow, (*hirundo edulis*) the builder of those eatable nests which constitute so great a delicacy at eastern tables. The bird is of a jet black colour, greatly resembling the martin in shape, but smaller in size, and has remarkably short legs, so as to be unable to rise from the ground, if happening to fall or settle upon it. They build their nests in fissures or cavities of the rocks, especially where they open to the south; and the cock fixes a smaller and more clumsy nest close to the one built by the hen for hatching her eggs. During certain winds, particularly the south-west, these birds remain in a state of torpor, and give no other sign of animation than a tremulous motion over the whole body. Their nests are generally supposed to be made of gelatinous substances found on the shore and rocks; but Haensel, the Danish missionary, who resided so long on those islands, considers it as much more probable that they are composed of the gum of a peculiar tree called the Nicobar cedar; and often observed innumerable flocks of the swallows fluttering around the blossoms and fruit of these trees.

The most formidable animals on these islands are crocodiles, which are found in great numbers wherever there are fresh water lakes and streams. They are of two kinds, viz. the proper crocodile, which is said never to attack living creatures, but to subsist on carrion; and the black kayman, which is of a smaller size than the other, and which seizes with the greatest ferocity every animal that comes in its way. Serpents are numerous in some places; but the custom prevalent among the natives of setting fire, two or three times a year, to the long grass on the mountains is supposed to check their increase. Some of them are extremely venomous, and the bite of one singular species, with a broad head and mouth like a frog, with very red eyes, has been known to prove fatal in the space of half an hour. There are not many scorpions; but there is one species of a red colour, and unusually large size, which is said to be peculiarly poisonous.

The surrounding sea abounds with fish of various descriptions and excellent quality. All kinds of shell-fish, turtles, cockles, and crabs, are found on the coast; and nothing can surpass the display of beautiful shells of the rarest kinds which are scattered along the shores.

The Nicobar islands are thinly inhabited, and some of them are entirely destitute of inhabitants. The united population of Nancowry and Comarty, which are considered as the most populous, is not supposed to exceed 800. The natives themselves are so sensible of the scanty population of their islands, that they are very desirous to increase it, by seducing the Lascars in the country ships to remain among them. These people are of a copper colour, and rather low in stature; but well formed, and remarkably strong and active. Their countenance resembles that of the Malays, and is by no means pleasing in features or expression. They have small eyes, in which the white part is of a yellowish hue; small flat noses, large mouths, thick lips, black teeth, and long ears, with wide holes in the lobes. The hind part of their head is flat, (being compressed during infancy,) and their strong black hair cut quite round and close. The women, who are represented as extremely ugly, have their heads completely shaved; and the men also shave their eye brows, while they suffer the little beard that they have to grow.

The clothing of the men consists of a narrow piece of cloth, about three yards in length, which they wrap twice round their waist; or, drawing it very tightly between their legs, pass it through the girth behind, leaving the end of it to hang downwards; a circumstance which is supposed to have occasioned the mistake of Kioping, a Swedish navigator, who describes the inhabitants of these islands as men with tails. The women wear a piece of cloth, commonly of a blue colour, about a foot wide, fastened round their waist, and hanging down like an apron; but sometimes this covering is made of a sort of rush or dry grass, not interwoven, but hanging down in detached filaments. Both sexes are said to be fond of dress, adorning themselves at their festivals with leaves in a fanciful manner, and, in the presence of Europeans, putting on whatever old clothes they have received from them. They do not commonly use paint, but pride themselves upon the fineness of their skin, which they keep very clean.

Their villages, consisting of fifteen or twenty houses, are commonly built on the shore, under the shade of the cocoa-nut trees. The houses, which are generally spacious, are of a circular form, and are raised upon piles to the height of six or eight feet from the ground. This manner of building is intended to secure the habitation from snakes and rats; and, for this purpose, the pillars, besides being covered with a smooth leaf, have round flat pieces of wood near the top, to prevent the progress of these vermin. The flooring is in part made of slips of bamboo at small distances, to admit the light and air; and the entrance is through a trap-door at the bottom, to which the inhabitants descend by a ladder, which is drawn up after them. There is only one apartment, but several families, sometimes to the number of twenty persons, generally live in the same habitation, where they all sleep together, lying naked on the floors, with a kind of palm-leaf under them by way of mattress, but seldom with any covering above them. In those bays and inlets which are sheltered from the surf, these houses are often erected so near the margin of the water, as to admit the tide to flow under them, and wash away any filth collected below. The furniture consists in a few earthen pots, highly-polished cocoa-nut dishes, hatchets, knives, one or two sabres, a number of spears and fishing-nets; besides two or three palongs or boats belonging to each family.

Their food consists chiefly of the bread fruit of the mellory; yams, and other wholesome roots; fruits of various trees and shrubs; the flesh of pigs and fowls, which are very abundant in the islands, and being fed chiefly on the cocoa-nuts, are remarkably excellent as food; and a great variety of fish and shell-fish, which they are able to procure with very little difficulty. They eat immense quantities of pork, and cook their flesh-meat very slightly. They use as drink the milk of the cocoa-nut, and the juice of the cocoa-tree, which they call soura, and which they suffer to ferment till it acquires an intoxicating quality. They are fond of smoking tobacco, and drink all kinds of spirits with the utmost greediness. Their mouths are continually full of betel or areca nut.

The principal employment of the men consists in constructing and repairing their huts, which occupies a considerable portion of every year, and in fishing or trading to the neighbouring islands; while the women attend to the preparation of the victuals and the culture of the ground. They generally kill their fish with spears, which they throw with great dexterity; and frequently go out with their canoes at night with burning straw to to allure the fish into shallow water. They are a remarkably indolent race, and spend the greater part of their time in feasting and dancing. Their music is of the most simple description, plaintive and monotonous, but not without harmony; and their dances are equally heavy and inanimate; the men and women forming a circle with their hands on each other's shoulders, moving slowly backwards and forwards, or from side to side, beating time with their feet. Their only musical instrument is a hollow bamboo, about two feet and a half in length, and three inches in diameter, along the outside of which is stretched a single string, which is pláyed after the manner of a guitar, and accompanied with the voice.

The language spoken by these islanders is founded on the Malay, and particularly resembles the dialect of Pegu. There are no books or vocabularies among them to assist in the acquisition of it, which appears to be a very difficult task to Europeans. The Danish missionaries were never able to make much progress in the study of it. The habits of the natives present considerable impediments to every learner. The language itself is very poor in words and expressions, and the natives are so taciturn, or rather indolent, that they speak too reluctantly or indistinctly to be easily understood. Many of them speak a corrupted Portuguese, and various European words are used in their conversation with strangers. They entertain a high veneration for those who are able to read and write, and believe that by these means Europeans can accomplish supernatural effects.

They cannot be said to carry on any regular commerce, but are frequently visited by trading vessels for the sale of the excellent cocoa-nuts which the islands produce; and numbers of Malays and Chinese arrive regularly in quest of the birds' nests already described. Those which are white and transparent are the most highly esteemed, and are sold at Batavia for ten dollars per caty, (1¾ lb.) which usually contains about seventy of the nests; but they bear a much higher price in the ports of China. The natives have no money of their own, nor do they attach any value to the coins of other countries, except as ornaments, but they are expert judges of the purity of the precious metals. The articles which are most in request among them are, cloth, hatchets, sword-blades, tobacco, and arrack; and a hundred of their finest cocoa-nuts may be procured for a yard of blue cloth. Some of them carry those articles to other islands, which are more remote from the tract of trading vessels, and exchange them for canoes or other articles of native manufacture.

These islanders have scarcely any form of government or legal control to which they pay subjection. In each village there is a captain or head man, styled Omjah karru, "the great master of the house," who owes his station chiefly to his superior talents and intelligence, but who must content himself with friendly remonstrances, and never attempt to command. All the preference shown to him consists in this, that when a ship arrives he is allowed to go first on board, and to make the bargain, if there is any thing to barter. These chiefs are usually more fluent in speech than their neighbours, and are commonly good-natured men, disposed to preserve peace among the people. They are very inoffensive to one another, and readily exchange kind offices with their friends. Theft, robbery, and murder, are rarely perpetrated among themselves; but, when attacked or injured by strangers, they fight with the greatest resolution and spirit. When it happens occasionally that the men quarrel in their drinking parties, or that a general dispute arises between their villages, a formal combat ensues. The captains of the neighbouring villages assemble, and the combatants being chosen, are furnished with long sticks of the mango tree, of a certain thickness. All who have any private quarrel usually embrace the opportunity of settling their disputes, and are in like manner supplied with the appropriate weapons. Two of the combatants then step out, and beat each other about the back and head till one of them is obliged to give up, and are followed by the other couples in succession. All are convinced at the conclusion, that whoever was compelled to yield was the offending party, and peace being thus restored, the matter is often terminated, as it began, by a drinking entertainment.

Both sexes live from their infancy without any restraint, and almost in promiscuous concubinage. They rarely marry till past the prime of life; and even then are continually dissolving their domestic connexions, and forming new matches, without any other law than their own choice.

The changes of the moon (by which chiefly they mark the progress of time,) are always observed as seasons of festivity, when they adorn their bodies and houses with garlands and leaves, and spend the day in singing, dancing, eating and drinking. There prevails among them a universal hospitality, without the smallest ceremony. They seldom speak or offer any salutations as they pass each other, and will rarely open their mouths as long as they can express their meaning by signs; but any one may enter the houses in his way, and sit down till he is rested, and help himself to any food within his reach, or at least be directed by the family with a signal of the hand to do so, and finally depart, without a single word being uttered on either side, unless he chooses to begin the conversation, when he will receive a friendly answer, and be dismissed with hearty good wishes. They are altogether a harmless, honest, good-natured, and gay-tempered race; but lazy, gluttonous, and drunken in the extreme; and sometimes, when their passions are roused by jealousy or revenge, are capable of committing the greatest excesses. Owing probably to their inaction and debauchery, they are not long-lived; and few of the men have been observed to be above 45 or 50 years of age. Yet they are not liable to many diseases, and except the œdematous swelling of the legs, known by different names in the east, and occasionally a mild species of small-pox, their most prevalent disorders are fevers and cholics. Their physcians or conjurers employ few internal medicines, except some potions from herbs, and in most cases use friction with oil; but as all the more dangerous diseases are considered as proceeding from the devil, the constant practice, even when medicines are administered, is to expel the demon by incantations. In those operations they exhibit the most astonishing feats of legerdemain; though stark naked during the process, they will appear to extract large stones, yams, &c. from the bodies of their patients. When their tricks have no effect, they sometimes pretend that the devil still frequents the house or vicinity, in the person of some man or woman, sucking all the power of healing out of the patient; and whatever individual the pater (as they call those jugglers) shall name as the witch, is, without farther inquiry, instantly put to death. At other times, they pretend to have laid hold of the evil spirit, and drag him down to the shore, where they make a show of putting him on board a small raft of light wood, which is instantly towed out to sea by a couple of well-manned boats with the utmost expedition. On the third day he must perish; but should he be driven on shore before that time in the vicinity of another village, he is understood to inflict the same evils there which he had been prevented from doing in the former place; and the keenest enmity is forthwith kindled between the two townships, which nothing but the above-mentioned combat can settle. They ascribe eclipses of the sun or moon to the same evil genius, who is supposed to be attempting to drown these luminaries; and, in order to drive him from such an enterprise, the whole inhabitants assemble with their gong-gongs, which they beat with great violence, while others are darting their spears in the air to repel the assailant.

When any one dies, his clothing, implements, livestock, and all his moveable property, are buried along with him; and, while the women make loud lamentations, the men are busily employed in drinking and smoking. But one of the most extraordinary ceremonies is the annual festival observed in honour of the dead. After spending the greater part of the day in a convivial manner, they repair to the burying place, where the woman nearest of kin to the deceased digs up the corpse, cleans the skull from the adhering earth and decayed flesh, laves it plentifully with the milk of the cocoa-nut, rubs it over with an infusion of saffron, and, having wrapped it carefully in a piece of new cloth, deposits it again in the grave. After spending the whole night in those melancholy rites, the ceremony is concluded by a feast on the following day.

These islanders have very confused ideas of a Supreme Being, and have scarcely any word in their language to express the notion of God. They speak of him by the general term Knaller, "above," or "on high," and believe that this unknown being is good, and never inclined to do them any harm. But they are perpetually occupied in all their religious ceremonies with the evil spirit, to whom they ascribe the creation of the world, and on whom they lay the blame of all the crimes which they commit. They are not properly idolaters, like most of the other oriental nations, but employ a variety of superstitious observances, to counteract the mischievous designs of the devil. In every village a high pole is erected, with long strings of ground rattans hanging from it, as a mean of averting the demon's presence; and, upon any appearance of a storm, in which he is supposed to visit them, the villagers fix around their boundaries small sticks, holding in a split at the top a piece of cocoa-nut, tobacco, or certain leaf, either as a peace-offering, or an object of antipathy. But their chief confidence rests on the power of their paters to catch and control these invisible adversaries. See *Asiatic Researches*, vols. ii. iii. iv.; Haensel's *Letters on the Nicobar Islands;* Valentia's *Travels*, vol. i.; and *Neptune Oriental.* (*q*)

NIEVRE, the name of one of the central departments of France, which derives its name from the small river which has its source in it. It comprehends the old province of Nivernois, and is bounded on the north by the Yonne, on the west by the Cher, on the south by the departments of the Allier, and the Saone and Loire, and on the east by the Saone and Loire, and the Cote-d'Or. Its superficial extent is about 28.000 square miles. The surface is hilly, and covered with wood; and its soil is in general barren and sandy. The principal productions of the department are corn, wines, coal, cattle, fish, iron and mineral waters. It has a number of forges and manufactories of hardware, woollen stuffs, leather, and glass. The principal towns are,

Nevers,	10,150
Clamecy,	5,338
Cosne,	4,709
Chateau-Chinon,	3,156

Nevers is the capital of the department. The forests occupy about 400,000 acres, of which more than three-fourths belong to individuals. Population 251,158. Contributions in the year 1803, 2,145,556 francs. See NEVERS.

NIGER. See AFRICA.

NIGRITIA, is a name sometimes applied to the central districts of Africa, and is synonymous with Soudan.

NILE. See ABYSSINIA and EGYPT.

NISMES, an ancient town of France, and capital of the department of the Gard, is agreeably situated on the declivity of a hill, not far from a small river called the Vistre. The streets are irregular, narrow, and winding, and the houses in general ill built. In the suburbs, which are very large, the houses are of a better description. A number of neat and modern buildings are erected on the Boulevards. Among these are a new hall of justice, in the Greek style, a handsome hospital, and a large theatre. Nismes has been long celebrated for its Roman antiquities, which are both numerous and splendid. The *Maison Quarrée*, which is in reality a parallelogram, is 76 feet long, 38 broad, and 64 high. It has six columns in front, and 11 on each side, reckoning twice those at the angles. Eight of these columns are engaged in the walls of the building, and the other three entirely insulated. Out of the 30 columns which the building contains, 10 are free, and 20 engaged. They are all of the Corinthian order, and are 27 feet 3 inches and 3 lines high, French measure, and 2 feet 9 inches in diameter. The capitals, which are decorated with the leaves of the olive-tree, are of great beauty; and the ornaments of the entablature are equally fine. Great excavations have been lately undertaken, from which it appears that it was surrounded by a splendid colonnade, at a considerable distance all around, bearing a massy cornice of excellent workmanship.

Near the Maison Quarrée is the ampitheatre. This superb remain of antiquity was copied from the Coliseum at Rome. It is constructed of the finest stones, which are held together by cramps of brass. They were quarried at Nismes, and some of them are 18 feet long. The amphitheatre is about 407 feet long, from east to west, including the thickness of the façade; and its smallest diameter about 317 feet at the four cardinal points, and at equal distances there are 15 arcades. The great arch of this fine building is still entire; and its arcades, columns, and porticos are in excellent preservation.

The building called the Fountain, is one of the finest things of the kind in France. It contains the remains of Roman baths; and its mass of limpid waters is conveyed through the town by a canal, flanked with hewn stones, and bordered with ballustrades. The ancient temple, which is generally called the Temple of Diana, or the Temple of the Fountain, consists of two rows of arcades. The interior displays a large and fine vaulted hall, adorned with 16 columns, carrying a rich cornice, on which rests the vault. There are also 12 square niches, destined to receive statues, and the whole is surrounded with a gallery. The columns are of the composite order, with very rich capitals, all of them different, and the ceilings are designed with great elegance.

Behind this temple is an eminence, on which is erected what is called the Great Tower, built of lithographic limestone, in small squares like bricks. It is about 120 feet high, and was formerly surrounded with a circle of open columns. It has been considered by some as a lighthouse, by others as a signal-post, and by others as a tomb. It is now, however, regarded as a pantheon, and within it are deposited a rich collection of ancient statuary, found at Nismes. There is likewise at Nismes an ancient gate, on which there is an inscription, stating that the gates and walls of the city of Nismes were built by Augustus in his eleventh consulate, *i. e.* in 738 or 739.

Nismes possesses a royal college, with a library containing above 30,000 volumes; an Academy of the Fine Arts; and a Society of Medicine and Agriculture. The manufactures are silk stuffs, stockings, ribbons, and leather; and it carries on an extensive trade in raw and wrought silk, corn, dried fruits, olive oil, and wine. Population about 14,000. East Long. 4° 21′ 15″, and North Lat. 43° 50′ 8″. See Maucomble's *Hist. des Antiq. de Nismes*, Nism. 1789, and Millin's *Voyage dans les Departemens du Midi de la France*, tom. iv. p. 212.

NOOTKA SOUND, is the name of a bay in the South Pacific Ocean, on the north-west coast of America. Its estuary is situated in 233° 12′ of East Long. and 49° 33′ of North Lat. It was discovered by Captain Cook in 1770. The inhabitants of the town and villages amount to about 2000. A company of British merchants, called the King George's Sound Company, established a settlement here in 1786, for carrying on a fur trade with China. It was, however, seized by the Spaniards in 1789, and the settlers were carried to Mexico, where they were set at liberty.

NORFOLK, a maritime county of England, is bounded on the north and east by the German Ocean; on the south by the rivers Waveny and Little Ouse, which divide it from Suffolk; on the west by Cambridgeshire and a small part of Lincolnshire. From the county of Lincoln it is separated by the river Nen; from that of Cambridge by the Great Ouse—except where it projects across this stream near its mouth, for a short space, and has no natural boundary. Excluding this little portion, the whole of Norfolk lying eastward of the Great Ouse would thus be almost completely surrounded with water,—since the head of the Waveny, and that of the Little Ouse on the south, are only nine feet asunder, while the former of those rivers flows into the ocean on the east, the latter into the Great Ouse on the west. A narrow causeway forms the passage through the marsh which lies between their sources, near the village of Lopham. The shape of Norfolk is not far from elliptical: the longest diameter, extending in a westerly direction from Yarmouth to Wisbeach, measures about 60 miles; its shortest diameter extending, of course, from north to south, between Wells and Billingford, measures somewhat less than 40. The superficial extent is estimated at 2,092 square miles, or 1,338,880 acres. It is divided into 33 hundreds, and farther into 756 parishes; it contains one city, and 29 market-towns, four of which are sea-ports. It lies in the diocese of Norwich, and sends twelve members to Parliament.

The aspect of Norfolk is very uninteresting. In general, the surface presents little artificial beauty, and almost a dead uniformity of level. Much even of the cultivated ground is destitute of ornament; and large tracts of heath, without a single tree to hide their unvaried barrenness; sandy wastes in one part; marshes in another; lazy streams, with here and there a shallow reedy lake, give a character of insipidity, or even dreariness, to many districts of the county, particularly in the south-east. The cottages and small farm-houses, too, being in many cases formed of wattle and dab, or of lath and plaster, and covered with thatch, are of a kind with the adjoining scenery, and tend to aggravate its dulness. This general description is not, however, equally or at all applicable in every quarter. About Norwich, and northward, the face of the country is considerably more pleasing. Here the ground is a little broken by moderate elevations; and the prospect is farther enlivened by the more frequent appearance of hedge-rows, coppices, and plantations, as well as by a greater proportion of neat brick farm-houses, and elegant mansions of a higher order.

The flat surface of Norfolk naturally terminates in a flat sea coast. The stratum of chalk, which begins in Dorsetshire, and forms so picturesque a shore all round the south of England, reaches through Norfolk also, and ends with it; but this, its northern extremity, seems attenuated or depressed, and is rarely visible. Here, instead of high rugged cliffs, and deeply indented bays, we find a low unbroken beach, covered with shingles or sand, and frequently with ooze. Nearly all the inlets have been formed by rivers; and the passing sailor reckons his progress, not by the appearance and disappearance of mountains and promontories, but by the succession of church spires, which, owing to the levelness of the country, he is enabled to discover at a considerable distance inland. The rock of Hunstanton, at the north-east corner of the county, usually called *St. Edmund's Point*, (from a vague tradition of King Edmund's having landed there, when he came to take possession of East Anglia,) is the only eminence of note on the whole coast. Westward of this, as far as Lynn Regis, extend what are called the *Mud Cliffs;* and southward, after some inconsiderable elevations in the neighbourhood of Cromer and Sheringham, occur the *Meals*, or *Marum Hills*, a series of banks formed by the sand and pebbles on the beach having been thrown into heaps by the violence of the waves, and bound together by the matted roots of various *sea-reeds* (the *Arundo arenaria*, *Arenaria peploides*, *Carex arenaria*, and others,) which are found on them in great quantities. The Meals reach to Caister, within two miles of Yarmouth: they form a kind of natural sea-dyke, which, like the artificial ones of Holland, preserves a valuable portion of the country from continual inundation. Similar banks running parallel to the coast, under water, answer a less beneficial purpose. Being discoverable only when the tide is near the lowest, and lying in several cases far off the shore, they frequently prove fatal to ships. The most remarkable is Yarmouth bank; which partly redeems its dangerous qualities by the ample security it imparts to the *Roads*, a deep channel running between it and the land, wherein a large fleet may ride safely during very tempestuous weather.

The chief rivers of Norfolk are those which contribute to form its boundary, and have already been enumerated. The *Great Ouse* rises near Brackley in Northamptonshire: after being joined by the Lark and the Cam, it changes its course from north-east to north, receives the little Ouse from the east, and flows between Cambridgeshire and Norfolk till within a short distance of its termination, when, having entered the latter county, and being farther augmented by the Nar from the eastward, it falls into the sea about two miles below the harbour of Lynn. The length of its course is estimated at sixty miles; through twenty-four of these it is navigable for barges; boats ascend it as far as Bedford. *Lynn-deeps*, as its mouth is named, affords good anchorage for large vessels, and is much frequented by them. The Ouse flows so gently, that it resembles a canal, and well nigh equals one in regard to utility for trade; by means of it, Norfolk enjoys a communication with no fewer than seven inland counties; but, to counterbalance this advantage, the same peculiarity renders it extremely subject to inundation. About the equinoxes in particular, and especially at the full moon of the autumnal one, it is liable to a species of flood, which, from its impetuosity, the inhabitants are accustomed to denominate *an eager*. The tide flows up the channel with extraordinary fury, overwhelming every obstacle, and frequently causing extensive mischief; even the water-fowls shun it on such occasions. Next in importance to the Great Ouse is the *Yare*, at the mouth of which stands the principal sea-port of the county. Like the Humber, this stream has no particular source, but forms the trunk in which a number of subsidiary rivers unite. Of these, the chief are the *Wensum*, which rises near West Rudham, and, flowing to the eastward, passes the city of Norwich, and partly environs it; the *Bure*, which rises on the north side of the county, near Hindowelston; and the *Waveny*, which rises on the south side near Lopham, and running in a curved direction, forms the boundary of Suffolk through its whole course. At the same Lopham, as we have already observed, rises also the *Little Ouse*, which, proceeding to the opposite quarter, completes the northern boundary of Suffolk. It joins the Great Ouse at Littleport, among fens on the borders of Cambridgeshire, being navigable as far as Thetford, where it receives the Thet.

Like the Great Ouse, these other rivers, rising among swamps, and flowing through a level country, proceed at a very slow rate, and contribute to keep the adjacent lands in a wet state, and to infect the atmosphere with vapours. In some instances, their progress being obstructed by the accumulation of mud and rubbish in their channels, they have spread themselves over their banks, and formed in their passage various sheets of shallow and almost stagnant water, which, in the provincial dialect, are termed *broads* and *meres*. These meres occur chiefly in the district from which the Yare is fed. *Breedon Broad*, the largest of them, measuring three miles in length by one in breadth, lies at the junction of the Waveny and Wensum, where the Yare is said to begin. One or two of nearly equal dimensions, and several of smaller, occur in the same neighbourhood; a few in other parts of the county. They are plentifully supplied with fish and aquatic birds. In the fenny districts, also, many temporary lakes are formed during winter, and resorted to by multitudes of wild fowls, for catching which it is usual to erect decoys all around.

The general structure of Norfolk is well suited for the formation of canals; but the number of its deep and smooth rivers in a great measure supersedes their utility. Except a short cut from Wisbeach to the Nen, intersecting a small part of the county, and another from Eau-bank to Lynn, the improvements on inland navigation have been limited, in Norfolk, to widening and cleaning the natural channels, and in a few instances constructing sluices on them. Private estates in the vicinity of such a stream are often furnished with a little canal, by which they communicate with it, for transporting their corn, and bringing back their manure.

In regard to the nature of its soil, this county exhibits considerable variety. The predominant ingredients are sand and clay, intermixed in different proportions—at one time forming a compound so light and arid, that it even drifts in the wind, and is almost bare of vegetation—at another, a stiff tenacious kind of land, distinguished for the number and copiousness of its springs. The former characteristic prevails in the southern and western districts of the county, the latter (much less extensively) in the interior to the east and south-east of Norwich. North and north-east of that city, for several miles, the finest combination is met with; it is a sandy loam, resembling that of Belgium, and equal in value to the most fertile parts of it. In some quarters of the coast, as at Marshland, near the Wash, and about the mouths of the Waveny and Yare, the ground is formed of ooze by deposition from the sea; unless secured by embankments, as is the case in Marshland, it is generally overflowed during the wet months, and requires to be drained in spring before it can be used as pasture, for which it is then peculiarly adapted. In the south-west extremity of the county, there is, moreover, a portion of that immense fenny tract which extends into all the neighbouring counties. It had long been partially drained; and the well-known *Bedford Level* at length completed its improvement. The following table of the Norfolk soils, by Mr. Arthur Young, professes to show the different species, with their respective extents. Though evidently imperfect, and in some respects erroneous, it is worth subjoining.

	Square Miles.	*Acres.*
Light sand, - - - -	220	148,800
Good sand, - - - -	420	268,800
Marshland clay, - - -	60	38,400
Various loams, - - -	900	576,000
Rich loam, - - - - -	148	94,720
Peat, - - - - - - -	82	52,480

There are no minerals of importance in Norfolk; no metallic ores, no coals have been discovered; indeed, the geological structure of the ground nearly precludes the hope of finding any. The layer of *clunch* or indurated chalk, which occurs every where beneath the surface, appears to cover all the more productive beds of rock, and even to render it uncertain whether they exist here. The clunch itself is burnt for lime, or used in the natural state, as a building stone. A more durable substance, used also for the latter purpose, is the black flint, which is found in masses, imbedded in a softer stratum of chalk, that lies above the clunch. Many houses in Norwich are formed of this material; it is brought from Mousehold-heath, where it is dug out of pits. Brick is much more extensively employed; and clay of excellent quality, for making it, abounds in various quarters. There occurs likewise some clay well fitted for earthen ware.

The climate is reckoned considerably below the general average of England; being exposed both on the north and east, the county experiences the full rigour of the winds which blow from those points, and which are observed to be extremely prevalent here. It is this circumstance, more than any other, which gives to vegetation so languid and backward a character during the early seasons of the year. The moisture with which the air is frequently loaded contributes to the same effect, and is still more pernicious to animal health. In the fenny districts, intermittent fevers are so general as in some sort to be endemic; when a stranger is seized with an ague, the people talk of him as being *arrested by the bailiff of Marshland*. The neighbourhood of the sea, or swampy land, is the cause of this dampness; and, in the interior of the county, where both conditions are wanting, the coast being distant, and the soil sandy, the air is dry and perfectly salubrious.

With so few apparent advantages as we have described it to possess, Norfolk might naturally be expected to owe its share of distinction to other causes than its agriculture. But the fact is not so. The ingenuity of the husbandman has here been exerted with remarkable success in struggling against the obstacles of nature, or giving free scope to her productive powers. Since the middle of last century, improvement has rapidly proceeded; and more corn was at one time raised within this county than on any equal space elsewhere. A hundred years ago, half the county consisted of rabbit-warrens or sheep-walks; and, in 1793, it was computed that above a million's worth of grain went out of it annually. Since that period, Norfolk has participated in the stimulus given to agriculture generally, over the kingdom; and, though no longer supreme, [illegible] ranks among the highest in the scale of [illegible] ness. Enterprising proprietors have encouraged farmers of large capital to enclose the waste lands, to bring the marshes and fens under the dominion of the plough; and those unpromising tracts have been found to repay the labour bestowed on them with the most exuberant crops. By a skilful system of husbandry, enriched with native and foreign inventions, and quickened in its action by various accidental circumstances, Norfolk, naturally unfertile, in part even noxious, has been made to rival in agricultural wealth the vales of Taunton and Evesham.

Farms in Norfolk are usually large; sometimes the rent exceeds £4000. Hence, in some degree, arises the superior adventurousness and the extreme assiduity with which its husbandry is conducted. One characteristic which strikes the agricultural traveller here, in particular, is the high state of pulverization to which the soil is reduced, and the care with which it is kept free of weeds. For this purpose repeated ploughings are employed, and afterwards the operation of wheeled drags and harrows, which are drawn by horses kept at a trotting pace. Another characteristic, but no longer confined to Norfolk, is the unbroken succession of crops, or at least the total disuse of fallowing. The methods of dispensing with this awkward practice have now become common, though Norfolk was once solitary in the use of them. Among the green crops applied to this object, the turnip crop, one of the most valuable, was primarily introduced here. It came from Hanover. Viscount Townshend, when attending George I. in his electoral dominions, was struck with the utility of this vegetable, and brought some seeds of it with him into his estate in Norfolk, from whence it subsequently spread into all corners of the island. The other green crops are potatoes, carrots, beans, peas, vetches, buckwheat, cole-seed, and every sort of artificial grass. Of the white crops, wheat is rather extensively sown; stiff loamy soils will sometimes yield ten quarters of it to the acre; oats are raised more sparingly, only as a shifting crop; and none of the produce is exported. But the great article is barley. It usually occupies one-third of all the arable land in the county; and above one half of it is sown on ground previously cleaned by turnips. The produce of an acre will sometimes rise to eight quarters. It is converted into malt, and exported in that state. Both the wheat and the barley are commonly sown in drills, an operation which is effected by the aid of several ingenious machines; sometimes they are planted by a dibble with the hand. The usual mode of arranging their succession is by what is called a six-course-shift. The first year wheat is sown; the second, barley, with or without clover; the third, turnips; the fourth, barley or oats, with clover; the fifth, this clover is mown for hay; and during the sixth, the ground is depastured, and ploughed up for wheat, as in the beginning. According to this system, the average rate of increase for the whole county is three quarters of wheat per acre, and four of barley; though, in the best soils, as we have already stated, it is greatly higher. Besides these principal crops, there are several which are raised occasionally, or in particular situations. Mustard and saffron are sometimes met with towards the borders of Cambridgeshire; and flax and hemp are cultivated to a small extent in the south.

Among agricultural implements of a peculiar form, the drill-roller of this county must not pass without notice. It is a large cast-iron cylinder, with projecting rings round it, at the instance of about ten inches from each other. Being rolled over the ploughed land, this instrument, by means of its rings, leaves ruts behind it, into which the seed, though merely scattered by the hand, naturally gathers itself, at least during the succeeding operations, and is thus simply and effectually deposited in regular rows. The *wizzard* of Norfolk is a temporary waggon, sometimes used in a busy period of harvest. It is formed by placing an additional pair of wheels under the shafts of a common cart, the body of which is, at the same time, elongated by two ladders or racks being fixed to the sides of it, and a third laid horizontally between them, for completing the bottom. Thrashing machines are universal; sometimes they are driven by steam. Moveable fences, now in general use over the kingdom, are said to have been first employed in this county. They prove serviceable, when it is required to consume a field of turnips or pasture, in successive parts.

Grazing is a secondary object, but still considerably attended to. The native sheep is a hardy animal, with horns and black feet. Its fleece weighs nearly two pounds; and the carcass, when fattened, about eighteen per quarter. It is considered as well suited to the soil and husbandry of the county, being accustomed to feed close, and endure penning. The wool was formerly classed in the third rank among native breeds; but lately it has been discovered that the neck part is equal to that of the Spanish sheep. The Norfolk cow, a little animal of a brown colour, with short up-curved horns, is now seldom reared. It has in a great measure given place to the Suffolk breed, a polled dun-coloured species, less calculated for barren pastures and hard weather, but yielding a larger quantity of milk. In some of the fenny districts peculiarly liable to inundation, the management of these animals constitutes the main business; and large quantities of butter, procured from them, are exported, under the name of Cambridge butter. In general, however, the grazier's aim is to prepare the cattle themselves, not their produce, for the market. At the fair of St. Faith's, (a small village near Norwich,) which is held about Michaelmas, the Norfolk graziers are accustomed to purchase large droves of Highland Oxen, *Scotch runts*, as they are named, which, when admitted to the rich pastures in the east of the county, soon lose the rugged meagre appearance they presented originally, and form a considerable item in the supply of the London market. Above 20,000 bullocks are annually taken to Smithfield, nearly three-fourths of which have come from Scotland, and been fattened in Norfolk; a few are Irish, the rest native.

The rivers of Norfolk furnish a copious supply of fish of different kinds. Perches are in such abundance, that 120 barrels are said to have sometimes been caught by means of two nets in a single day. The *ruffe* is a species of perch peculiar to the Yare. On the sea-coast, the supply is not less varied or abundant. Shell-fish is taken in several parts; but the most noted fisheries are of mackerel and herrings. To the latter Yarmouth owes its existence as a town; and the same cause has continued to procure it distinction since the period of the Conquest. In a successful year it has been known to export 70,000 barrels. exclusive of the home consumption, which probably amounted to 15,000 more. The trade is carried on under special regulations; and above 2000 fishermen from this port are employed in it. The herrings are cured by being salted repeatedly, and then smoked in houses contrived for the purpose.

From its geographical position, Norfolk enjoys a ready communication with several counties in the interior, and naturally forms the medium for exporting much of their superfluous home produce, and supplying them with foreign goods. Its harbours provide the inland counties with coals, wine, timber, groceries; and receive in return large quantities of cheese, corn, and malt. Yarmouth and Lynn, its chief ports, particularly the former, which has in later times become a station for the navy, have engaged to a considerable extent in the foreign as well as coasting trade. Their ships take a share in the Greenland fisheries, and visit the Baltic and the south of Europe. Wells, Cromer, Blackney, Burnham, and Clay, though partially concerned in the corn trade, may rather be regarded as fishing towns. The entrance and the neighbourhood of all these harbours are beset with danger: and the habit of surmounting it renders the seamen of this coast among the hardiest and most expert in England.

Norfolk was distinguished as a manufacturing county long before it was known as an agricultural one. It is seven hundred years since Worsted became noted for the woollen stuffs which still bear its name, though the place itself has now decayed to an inconsiderable hamlet, and the trade is removed. The surrounding district has continued to work principally from similar materials,—converting its wool, with various intermixtures of silk and mohair, into serges, crapes, shalloons, damasks, bombazines, shawls, and every sort of fancy goods. In this trade, the capital city has long taken the lead; and the introduction of machinery has of late tended still farther to collect the workmen within a closer neighbourhood. The manufactures of Norfolk are now almost synonymous with those of Norwich and its vicinity. A more detailed account of them will naturally fall to be given when the latter is described.

According to the several enumerations made by order of government, the population stood as follows: In 1801, there were 49,140 houses; and 273,471 inhabitants, of whom 129,842 were males, and 143,529 females; 61,791 being employed in agriculture; 38,181 in trade and manufactures. In 1811, the resident population had risen to 291,999, or 140 to the square mile; and in 1821, to 344,368; 145,999 being the number employed in agriculture, and 34*l.* the average net product, or the rent and tithes paid by each family.

As to the poor of this county, it appears from the reports laid before parliament, that in 1803, the number of persons receiving parish aid was 42,782, or 16 in 100 of the resident population. The expense so incurred was 175,361*l.* 8*s.* 3*d.* including 6031*l.* 17*s.* 9¾*d.* consumed in law suits, removals of paupers, and charges of overseers; including also 1459*l.* 18*s.* 7½*d.* consumed in purchasing materials for employing the poor; and omitting a calculated sum of 403*l.* 10*s.* given to vagrants and other non-parishioners. The money levied was at the rate of 14*s.* 11½*d.* per head on the population; the money expended immediately on account of the poor was at the rate of 12*s.* 10½*d.* per head on the population. Of the whole 42,782 there were 3998 maintained in work-houses at an expense of 11*l.* 5*s.* 1*d.* annually for each; and 38.786 relieved, not in work-houses, at an expense of 3*l.* 4*s.* 1½*d.* for each. The number of persons belonging to friendly societies was about 5 in 100 of the inhabitants.

See *Beauties of England and Wales*, vol. xi.; Kent's *View of the Agriculture of Norfolk*; and Young's *Farmer's Tour in the East of England.*

NORFOLK Island, an island in the South Pacific, discovered by Captain Cook in 1774. It is about fifteen miles in circuit, and contains about 1000 inhabitants. It is remarkable for the fertility of its soil, and the luxuriancy of its vegetation Some of the pines are from 150 to 180 feet high, and from 18 to 20 feet in circumference. E. Long. 168° to 98°. Lat. 29° 3'.

NORFOLK, a county of Massachusetts, bounded by Rhode Island S. W.; Worcester in Massachusetts W.; Middlesex N. W. and N.; and by Suffolk county, Boston harbour, and Hull bay, N. E. Length 30, mean width 13, and area about 400 square miles. Surface uneven rather than hilly. Soil productive in grain, fruits, and pasturage. Chief town, Dedham.

Population in 1810.

Free white males - - - - - - - - -	15,177
do. do. females - - - - - - - -	15,812
Total whites - - - - - - - - - -	30,989
All other persons except Indians not taxed	256
Slaves - - - - - - - - - - - -	0
Total population in 1810 - - - - - - -	31,245

Population in 1820.

Free white males - - - - - - - - -	17,451
do. do. females - - - - - - - -	18,754
All other persons except Indians not taxed	0
Total whites - - - - - - - - - -	36,205
Free persons of colour, males - - - -	123
do. do. females, - - -	131
Slaves, males - - - - - - - - - -	0
do. females - - - - - - - - - -	0
Total population in 1820 - - - - - -	36,459

Of these;

Foreigners not naturalized - - - - - -	340
Engaged in Agriculture - - - - - -	6,039
do. in Manufactures - - - - - -	5,415
do. in Commerce - - - - - - -	477

Population to the square mile, 91.

NORFOLK, a county of Virginia; bounded by Hampton Roads and Lynhaven bay, north; by Nansemond county of Virginia, west; by Pasquotank and Currituck counties, in North Carolina, south; and by Princess Anne county of Virginia, east. Length 30, mean width 20, and area 600 square miles. Surface level, and in part marshy. Soil generally thin, sandy, or wet and sterile.

Population in 1810.

Free white males - - - - - - - -	3,680
do. do. females - - - - - - - -	3,765
Total whites - - - - - - - - - - -	7,445
All other persons except Indians not taxed	587
Slaves - - - - - - - - - - - - -	5,647
Total population in 1810 - - - - - -	13,679

Population in 1820.

Free white males - - - - - - - -	4,550
do. do. females - - - - - - - -	4,092
All other persons except Indians not taxed	7

Total whites	8,649
Free persons of colour, males	417
do. do. females	475
Slaves, males	3 227
do. females	2,697
Total population in 1820	15,465
Of these ;	
Foreigners not naturalized	13
Engaged in Agriculture	2,807
do. in Manufactures	261
do. in Commerce	61

Population to the square mile, 25¾.

NORFOLK, a post-town, borough, and port of entry, Norfolk county, Virginia, on the right bank of Elizabeth river, immediately below the junction of its two branches, and 8 above Hampton roads. Lon. from the Royal Observatory at Greenwich, 76° 23′ W. and from Washington city, 0° 37′ E.

It is the most commercial town of Virginia; and in 1815, the tonnage exceeded 34,700, and stood next to Charleston of any of the Atlantic cities of the United States, south from Baltimore. It is defended by several forts, the most important of which is on Craney island, near the mouth of Elizabeth river, about 5 miles below the town. The United States Commissioners, who were appointed in 1818 to survey the lower part of the Chesapeake bay, reported, that Hampton Roads, though extensive, were capable of adequate defence, so as to prevent the entrance of an enemy's fleet.

Norfolk is connected with the commerce of North Carolina by the Dismal Swamp canal. This inland communication opens from Elizabeth river, 9 miles above Norfolk, and extends, through the Dismal Swamp, into Albemarle Sound. By means of this canal the produce of an extensive section of North Carolina finds a market at Norfolk.

This town contains a theatre, 2 state banks, a branch of the bank of the United States, a marine hospital, orphan asylum, an academy, Lancasterian school, Athenæum, and 6 or 7 places of public worship. The site is level, and so low in some places as to be marshy; but the streets are commodious, being well paved.

Population in 1810.	
Free white males	2,501
do. do. females	2,275
Total whites	4,776
All other persons except Indians not taxed	592
Slaves	3,825
Total population in 1810	9,193
Population in 1820.	
Free white males	2,187
do. do. females	2,431
All other persons except Indians not taxed	0
Total whites	4,618
Free persons of colour, males	229
do. do. females	370
Slaves, males	1,453
do. females	1,808
Total population in 1820	8,478
Of these ;	
Foreigners not naturalized	23
Engaged in Agriculture	0
do. in Manufactures	5
do. in Commerce	147

Darby.

NORTH, Department of the, is the name of one of the departments in the north-east of France. It was formerly part of French Flanders, and is bounded on the north by the Straits of Calais; on the west, by the department of the Straits of Calais; on the south, by those of the Samur and the Aisne; and on the east, by the Netherlands. It is about 140 miles long, and somewhere only 30 broad, and it contains about 2310 square miles. The soil is fertile, and well cultivated, and it is very productive in all kinds of corn, and in flax, tobacco, and hops. Coal is abundant, and it has large establishments for the manufacture of linen, woollen, and cotton goods. The chief towns are,

Lille	54,760
Douay	18,110
Bergues	5,081
Hazebrouch	6,611
Cambray	13 800
Avesnes	1,935

Lille is the capital. The forests occupy about 110,000 acres, the greater part of which belong to the government. Population, 774,450. Contributions in 1803, 4,558.519 francs

NORTH-WEST PASSAGE. See Polar Regions.

NORTHALLERTON, a market-town of England, in the North Riding of Yorkshire. It stands on the great north road, on a gently sloping ground, and consists chiefly of one street. The market-place is spacious, and is surrounded with very good houses, which are, in general, built of brick. The only public buildings are a spacious church, and a handsome house built for the steward of the bishop of Durham, who is lord of the manor. A new jail has been recently erected near the end of the prison, on the plan of Howard. Northallerton sends two members to parliament, and the right of election is vested in the burgage holders, who amount to about 180. Near Northallerton, in 1178, was fought the famous battle of the Standard. Population, 1300. See the *Beauties of England and Wales*, vol. xvi p. 194.

NORTHAMPTON, one of the interior counties of England, is bounded on the north by Leicestershire, Rutland, and a small part of Lincolnshire; on the east, by the shires of Cambridge, Huntingdon, Bedford, and Buckingham; on the south, by that of Oxford; on the west, by those of Oxford and Warwick. Its figure is elongated and irregular; and no county in the kingdom borders on so many others The greatest length is from Aynho in the south west, to Crowland in the north-east, and measures about 66 miles; the breadth varies from 30 to 8. The circumference is estimated at 216 miles; and the area at 1017 square miles or 650.880 acres. It is divided into twenty hundreds, and these again into 336 parishes: it contains one city and eleven market towns; lies in the diocese of Peterborough; and sends nine members to Parliament.

The surface is pleasing and variegated; broken into hills and dales, watered by numerous brooks and rivers, and generally covered with rich verdure. The numerous mansions and pleasure-grounds of the wealthier class add to its beauty. "The fertilitie," Norden observes, "salutarie ayre, pleasant prospects, and conveniencie of this shire, in all things, to a generous and noble mynde, have so allured nobilitie to plant themselves within the same, that no shire within this realme can answer the like number of noblemen as are seated in these parts. Of gentry it is so full, that it may be called the *Herald's Garden.*" Most part of the county was at a former period covered with wood; and considerable tracts of forest land still give a picturesque appearance to the eastern and the southern quarters. There are likewise some fens, but of no great extent.

Northamptonshire lies nearly at an equal distance from the eastern and the western border of England; and, though far from mountainous, it forms the most elevated portion of the great plain which comprehends all the south-eastern divisions of the kingdom. Its height above the neighbouring districts is demonstrated by the curious fact, that while no portion of itself receives a drop of water from any other county, it sends forth streams towards every point of the compass—to the German Ocean, to the Irish Sea, and the river Thames. The Great Ouse rises at Ousewell, near Brackley, in the parish of Farthingo; and soon entering Buckinghamshire, again touches its parent county at Old Stratford; from whence it pursues its long and devious course through Bedfordshire, Huntingdonshire, Cambridgeshire, and Norfolk, to Lynn-Regis. The Avon rises at Avonwell, near Naseby, flows westward into Warwickshire, and being joined by the Leam, which rises at the village of Hellidown, also in Northamptonshire, ultimately mixes with the Severn in Worcestershire. From the vicinity of Naseby there likewise springs another river, which being augmented at Northampton by a western branch, assumes the name of Nen or Nyne. After draining the greater part of the county, it falls into the Wash between Lincolnshire and Norfolk. It approaches the Welland, which falls into the Fossdyke Wash, after a long course from Sibbertoft in the west. The Charwell, a smaller stream, proceeds from Charwelton, passes Banbury, and joins the Thames at Oxford.

The Avon and the Ouse, when they issue from the county, are but rivulets: the Nen and the Welland continue in it till they become navigable rivers. By the aid of some improvements, completed in 1762, the Nen can be ascended as far as Northampton. It is little frequented except by coal barges. The internal communication is farther promoted by the Oxford and Grand Junction Canals, which cross each other at Braunston, on the western edge of the county, and both continue in it for a number of miles. From Blisworth, on the latter, a railway extends to Northampton.

In regard to climate, this county differs in no important respect from the generality of English inland counties, and is equally agreeable and healthful with any of them. The soil appears to be of a stiff loamy nature: in some places it is cold and wet, but for the most part fertile; the average rent and tithes of a square mile being 709*l.*; though large spaces are covered with wood, or subject to the right of common pasturage, and thereby rendered comparatively useless. Peterborough Fen, which is in the latter case, contains between six and seven thousand acres: the soil is said to be of a very high quality, but yields little; the right of keeping cattle on it, which is divided among thirty-two parishes, conjointly denominated the Soke of Peterborough, being scarcely deemed of any value by each individual.

In a state almost equally unproductive are the forests. They afford little else than a limited quantity of brushwood, and a range for the deer of the proprietors, and for the cattle of some adjoining parishes, which enjoy such a right over them. The forest of Rockingham, in the north of the county, is the largest. It formerly extended between Northampton and Stamford, measuring about thirty miles in length, by eight in breadth. But various concessions of the crown, in remote times, have greatly restricted its bounds; and it does not now contain more than 10,000 acres, scattered in successive portions over the district which it once completely filled. The property, with the timber, large and small, is at present vested in various persons; a right of pasturage, under certain restrictions, is reserved to the contiguous lands; and the claims of government are limited to the annual demand of a few braces of deer for the use of his majesty's household. The wardens and other chief officers are hereditary. Salcey and Whittlewood forests lie in the south of the county, the latter partly in Oxfordshire and Buckinghamshire. Salcey comprehends 18,447 acres; Whittlewood, 5424. In 1608, the first contained 15,274 trees fit for the use of the navy; the second, 51,046; but, owing to neglect or misconduct on the part of the overseers, those numbers had, in 1738, dwindled to 2918 and 5211. Salcey appears to be particularly fitted for the growth of timber. One oak in it is seventeen feet in circumference. Yet under the present management it scarcely yields a full grown tree on the acre. Charles II. granted all the most valuable perquisites of those forests to his son, the Duke of Grafton, with whose representative they still continue; the crown retains only the large timber, (which does not seem to bring in any thing in the shape of profit,) and receives annually a few bucks and does out of the 3000 which find subsistence there. The administration of the whole is committed to several officers, invested with various degrees of authority. The principal ones are hereditary: those appointed to take cognizance of trespasses on forest property, the *Verderers*, as they are called, continue to be nominated by the freeholders, but do not now hold any courts. Under the superintendence of those administrators, the forests were long ago divided into 93 separate coppices, intervening spaces of little extent being left vacant, and appropriated to the use of the keepers and their cattle. The small timber of each coppice is cut down every 21 years, during the first seven of which the deer are excluded by fences; the cattle during the first nine. All of them are, as usual, subject to rights of pasturage.

Exclusive of these half waste portions, Northamptonshire is generally in a state of respectable culture. It is distributed into rather large properties; but the farms are comparatively small;—they vary from 100*l.* to 500*l.* of rent. About half of the county is employed in grazing; and cattle, either native or imported, fattened for the London market, are the principal article of its produce. Wool is also provided for the internal consumption; and the dairy is an object of considerable attention, on some farms the sole object. The mode of husbandry, the animals and implements by which it is carried on, present nothing remarkable.

The limited manufactures of this county are principally concentrated about its capital, and will be noticed under that head. Besides these, there exist several fabrics of lace, woollen goods, and leather. Towcester is the chief seat of the first; Kettering of the second. Shoes are exported from various places; and saddlery articles, particularly whips, are prepared to a considerable extent at Daventry. There are likewise a few potteries, of ancient date, but diminutive importance.

According to the various enumerations made by order of government, the population of this county stood as follows: In 1801, there were 27,401 houses, and 90,818 inhabitants; of whom 63,417 were males, 68,340 females; 29 303 being the number employed in agriculture, and 31,426 in trade. In 1811, the resident population had arisen to 141,353, or 139 to the square mile; 70,262 being the number employed in agriculture, and 47*l.* the average net product, or rent and tithes of a family. In 1821, the population had risen to 163 433.

With regard to the poor, it appears that in 1803 the number of persons receiving parish aid was 20.534, or sixteen in the hundred of the resident population: the expense so incurred was 97.734*l.* 18*s* 2¼*d.* including 3287*l.* 1½*d.* consumed in lawsuits, removal of paupers, and charges of overseers; and omitting a probable sum of 158*l* 2*s.* given to vagrants and other non-parishioners. The money levied was at the rate of 18*s.* 3¼*d.* per head on the population: the money expended immediately on account of the poor was at the rate of 14*s.* 10½*d.* Of the total 20,534, there are 1313 maintained in workhouses, at an expense of 12,811*l.* 19*s.* 8½*d.*; and 19.221 relieved, not in workhouses, at an expense of 81,638*l.* 18*s* 4½*d.* The former, therefore, cost 9*l.* each annually: the latter, 4*l.* 4*s.* 11½*d.*

See *Beauties of England and Wales.* vol. xii.; and Pitt's *View of the Agriculture of Northamptonshire.*

NORTHAMPTON, the chief town of Northamptonshire, is situated in the south-east portion of that county, in West Long. 0° 44′, and North Lat. 52° 14′, at the distance of 67 miles from London, and 50 from Cambridge. It stands on the right bank of the Nen, at the confluence of the two principal branches of that river, which bounds it on the south-west, and over which two branches lead into it. The environs are fertile and pleasant; and the site itself, forming the summit and slope of a gentle eminence, contributes at once to the beauty and wholesomeness of the town. The streets are well paved and well lighted, and kept remarkably clean. A few houses are built of brick; but the more general material is a kind of red or yellowish sandstone, brought from quarries in the neighbourhood. Considerable manufactures, and a pretty extensive trade, gives an air of briskness and animation to the place, which is farther enlivened by the great north and north-west roads passing through it; so that, in point of convenience and agreeableness, Northampton ranks rather high among provincial towns.

It consists principally of two long streets, which intersect each other at right angles, and stretch nearly towards the four cardinal points. Near the centre is a large square, where the markets are held; it is said to be the finest market-place in England. Its sides contain many elegant shops and commodious dwelling-houses; in the middle stands a public cistern, at one end of which is a reservoir, called the *Great Conduit.* Lanes and alleys of inconsiderable importance occupy the rest of the town.

Among the public edifices of Northampton, its churches claim the first notice. It formerly contained seven; but three of these, with the parishes they belonged to, have now lost their individual existence. St. Peter's Church, a venerable pile, dates its origin from a period not much later than the Norman Conquest; it is regarded as a curious monument of ecclesiastical architecture, and is still in a good state of preservation. The churches of St. Giles and St. Sepulchre are likewise ancient buildings; and the church of All Saints, though rebuilt since the year 1675, when it was destroyed by fire, is not less singular in its appearance than any of them. It does not belong to the Gothic, Grecian, or any regular order. A square chancel stands at the east end, a tower at the west; and between them is a large chamber, measuring 74 feet by 73, from the centre of which four large pillars arise to support a flat roof, which again is surmounted by a dome. In addition to its four parish churches, the town contains a proportionable number of chapels appropriated to various classes of dissenters. The Castle-hill Meeting belongs to the Independents; and is remembered as being the scene of the pious Dr. Doddridge's labours during the two-and-twenty years previous to his death at Lisbon, of consumption, in 1751. There are likewise Baptists, Moravians, Methodists, and Quakers, in Northampton; but their places of worship attract no attention. The barracks, the three prisons, the county-hall, the theatre, are of little moment as buildings. The new jail, however, is constructed on the plan of Howard; it will hold 120 culprits. A more pleasing establishment, as well as a far handsomer edifice, is the General Infirmary, which stands at the eastern skirt of the town, upon the brow of a hill that gradually sinks to the south. The building consists of three stories above ground, and one beneath; it was completed in 1793, at an expense of 15,000*l.* and is said to be well adapted for the accommodation of sick persons, nearly 2000 of which sort receive relief from it annually, either as in-patients or out-patients. The institution is upheld by yearly subscriptions, and by the interest of numerous legacies. Other charitable foundations are, the Blue Coat School, the Brown School, the Green School, and the Girls' School; their revenues are inconsiderable. The Grammar School occupies a portion of the old church. St. Gregory, what was once the vicarage house, is now inhabited by the master. A public library has also existed for some time in the place; it is said to be conducted on a liberal scale, and to contain a valuable and augmenting collection of scientific and literary works.

Northampton is distinguished for the remains of monastic and feudal times, which are still to be traced in it, more than for its recent edifices. It once had a Priory of St. Andrew; an establishment for the Franciscans, or Gray Friars; one for the Dominicans, or Black Friars; and a College of All Saints, from which College-lane still takes its name The Austin Friars, also, once possessed a house in Bridge Street; and the Hospital of St. John is yet standing near it. In the thirteenth century there was a mint here. But what chiefly made the town important in those days were the castle and fortifications, both of which have now almost totally disappeared In the time of Edward I. the walls appear to have been of considerable strength. They were embattled, and had steps for ascending them in various parts: four gates gave admission from the north, south, east, and west sides, and were designated accordingly; near the east gate, "the fairest of all," according to Bridges, was a postern called the *Durn-gate* As in some other cities, the walls served for a promenade, to which the infirm, or indolent, were wont to resort for air and exercise. In winter they also constituted the best footpath from one extremity of the town to the other,—being wide enough for allowing six persons to walk abreast, and beyond comparison cleaner than the streets, as yet unpaved and muddy. The castle, which stood near the west gate, appears to have been founded on the ruins of some previous fortress in the reign of William the Conqueror. It was the scene of many fierce rencounters in succeeding periods of turbulence : it came at length to be used as a county jail ; was fortified by lord Brook for the Parliament in 1642 ; and finally demolished, twenty years after, by order of the king and council. Some traces of its foundation still exist ; and the general figure of the earthworks continues to be visible ; but the stones have all been removed.

The present extent and opulence of Northampton, though far from proportionate to its former dignity, are still considerable. In the year 1811 it contained 1576 houses, and 8427 inhabitants : both have greatly increased since that period. Its manufactures are stockings and lace, and particularly boots and shoes, large quantities of which are exported to foreign countries. Its trade is, of course, chiefly confined to exchanging the produce of the surrounding districts against articles of external or internal manufacture. For this purpose, three markets are held weekly—on Wednesday, on Friday, on Saturday. Its horse-fair is reckoned the largest in England, forming the centre of all the adjoining ones, and being regularly frequented by the dealers of London and York for the purchase of saddlery and harness, as well as of horses.

In its municipal constitution, Northampton is both a borough and a corporate town. In the former capacity it sends two members to Parliament, a privilege which it has enjoyed since the twelfth year of Edward I., when two of its representatives formed part of the Parliament held by that sovereign at Aston-Burnel, in Gloucestershire. As the number of voters, comprehending every inhabitant "who pays scot and lot," exceeds 1300, electioneering contests are frequent and violent ; and Northampton is celebrated, even among *open boroughs*, for the keenness with which many of these have been conducted. It is not yet forgotten that, in 1768, an affair of this kind cost the Earl of Spencer above 100,000*l*., and the two Earls of Halifax and Northampton nearly 150,000*l*. each. The first charter of incorporation was received from Henry II. ; it has subsequently undergone various alterations ; the last was in 1796. The corporation now consists of a mayor and two bailiffs, with such as have been mayors and bailiffs, a common council of 48 burgesses, a recorder, chamberlain, and town-clerk. The two latter usually continue for life, though subject to an annual election The magistrates are clothed with extensive judicial powers ; they are qualified to try criminal causes of all kinds ; but they seldom stretch their authority beyond the cognizance of petty larcenies, for which purpose a court of record is held by them once every three weeks.

NORTHAMPTON, a post town and seat of justice, Hampshire county, Massachusetts, on the right bank of Connecticut river, in the centre of one of the most beautiful sections of the United States ; 42 miles by land above Hartford in Connecticut, and 97 nearly west from Boston. This village contains, beside the ordinary county buildings, a bank, an insurance office, and printing office. Here are a number of manufactories, and in particular an extensive tannery and woollen cloth manufactory. The adjacent country is in a high degree delightful. The commanding summit of Mount Holyoke affords a sweep of landscape exceeded in but very few places of the world.

NORTHAMPTON, a county of Pennsylvania, bounded by Delaware river, or Sussex county, in New Jersey, east ; Bucks county, south-east ; Lehigh and Schuylkill counties, south-west ; Luzerne county, north-west ; and Pike county, north ; length, 37 ; mean width, 30 ; and area 1100 square miles.

This is one of the most diversified counties, not alone of Pennsylvania, but of the United States. It is traversed from north-east to south west by the Kittatinny mountains, or, as it is locally called in the county, Blue Ridge. This chain divides it into two very unequal sections. That south-east from the Kittatinny lies in form of a triangle, the base along the mountains, and perpendicular on Lehigh county, and contains within a trifle of 400 square miles. It contains also the townships of Lower Saucon, Williams, Bethlehem, Forks, borough of Easton, Hanover, Nazareth Upper and Lower, Allen, Lehigh, Moore, Bushkill, Plainfield, and Lower and Upper Mount Bethel ; with an aggregate population of 22,677. This part of Northampton county, with the exception of the townships of Lower Saucon and Williams, lies between the Kittatinny and South Mountain. The surface, though generally hilly, is as generally arable. The very remarkable slate and lime-stone formation which extends so distinctively from the Delaware to the Susquehannah, in the Kittatinny valley, is peculiarly striking in the lower part of Northampton. The limestone tract skirts the south mountain, and the argillaceous slate the Kittatinny, each extending from its respective base about half way across the valley. Though both are highly productive, in grain, fruits and pasturage, the limestone soil is rather stronger than that on the slate, and the features of nature less bold on the former than on the latter formation.

The townships of Lower Saucon and Williams are separated from the other parts of the county by Lehigh, and traversed by a ridge passing by Bethlehem, and interrupted by the Delaware, two miles below Easton. From many of the highest eminences of this range, the highly cultivated section we have been reviewing spreads before the eye like a vast garden, terminated by the distant Kittatinny mountains.

That part of Northampton, north-west from the Kittatinny mountains, extends over 810 square miles, and is remarkably broken into mountain ridges. Of these the Kittatinny is the only one which passes through the county in a direct line. Those to the north-west, are scattered, disunited, and lie rather in groups than extend in collateral ridges. All, however, have a general north-east and south-west arrangement, and leave intervening valleys of more or less width and fertility. As in other parts of Pennsylvania, the Northampton ridges receive local names in different places. The principal ones are, beside the South Mountain, or Lehigh hills, and Kittatinny, the Pokono, or Second Mountain, Broad Mountaid, Mauchchunk mountain, and some others. The soil in the valleys above Kittatinny, even where arable, is much inferior to that of the lower section already noticed. The general character of the latter is warm and productive. Above the Kittatinny the soil is principally composed of gravel and clay, and still farther above the Pokono, partakes so much of the clay as to become very cold and unproductive. The timber, hemlock and small pines. The rude character of this part of Northampton is seen by reference to its comparative population. Though embracing above 800 square miles, the aggregate number of inhabitants is only 8088, or within a trifling fraction of 10 to the square mile, whilst, as we have seen, the south-east section contains a condensed population of near 57 to the square mile.

The rivers of Northampton, are the Lehigh and Delaware. Creeks below Kittatinny, and advancing south-west from the Delaware Water Gap, are Coby's, Richmond, Martin's, Muddy creek, Bushkill, Monocacy, Calesoque, and Hockendocque; the three latter falling into the Lehigh, the residue into the Delaware.

Above the Kittatinny, the Delaware receives, immediately above the water gap, Broadhead's creek, partly from Pike and partly from Northampton. The mountain section of this county is, however, more particularly drained by the confluents of the Lehigh; these are, from the left, Tobyhanna, Dreck, Muddy, Big creek, and Aquanshicola; from the right, Quacake, Nesquehoning, Mahoning, and Lizard creeks.

Delaware washes the eastern border of Northampton, following its windings about 25, but in a direct line 20 miles; its course generally nearly north and south. Though obstructed with some shoals below that place, the Delaware is navigable for large boats to Easton, and for smaller vessels, and with more difficulty above that borough beyond the limits of Pennsylvania.

The Lehigh is emphatically the river of Northampton, having most of its sources, and the greatest part of its course, in that county. This stream demands particular notice, as it has now become the channel of transportation for the immense masses of anthracite coal found on the Mauchchunk mountain. The Lehigh, in fact, rises in Wayne, Pike, and Luzerne counties; but its various confluents unite near Stoddartsville, on the north-west border of Northampton, and again augmented by many mountain creeks, flows by comparative courses 25 miles to the mouth of Wright's mill creek. It thence turns to nearly south, and by a very serpentine course, but in a direct line of about 20 miles, passes Mauchchunk, and reaches Lehighton. Here it inflects to south-east, and continues in that direction 25 miles to Allentown, or town of Northampton. At Allentown the Lehigh is again turned by the South Mountain at nearly right angles, and assuming a north-east course down the foot of the mountain, flows past Bethlehem, and reaches the Delaware at Easton, 25 miles below Allentown. The entire comparative course of this stream is 85 miles. From near its extreme source to Trout creek, it separates Pike and Luzerne counties. From Trout creek to Rock Eddy falls, it separates Northampton from Luzerne. Below Rock Eddy falls to its passage through the Blue or Kittatinny mountain, its course is within Northampton county. Between its passage through the mountain and the mouth of Hockendocque creek, its course forms the limit between Northampton and Lehigh counties. Below Hockendocque to Bethlehem, it flows through Lehigh, and below Bethlehem to Easton through Northampton.

The Lehigh is truly a mountain torrent, and meanders through a series of natural scenes, not excelled, if equalled in the United States. The following table will exhibit its descent from Stoddartsville to Easton.

	Fall in Feet.
Stoddartsville, to the mouth of Nesquehoning creek, about two miles above Lausanne, and three above the village of Mauchchunk, - -	845
From Nesquehoning, to the Lehigh Water Gap,	160
From the Gap to Easton, - - - - - - - -	205
	1210

From Easton, to tide water in Delaware river, at Trenton, according to the last information, that stream falls about 100 feet. The Lehigh at Stoddartsville is, therefore, elevated 1310 feet, and at Mauchchunk, within a trifle of 460 feet, above the level of the Atlantic Ocean. According to the manuscript notes of Isaac A. Chapman, Esq. the average height of Kittatinny mountain, in Northampton county, is 1186 feet above the Lehigh, and Delaware rivers, at its base, consequently, 1491 feet above the Atlantic level. Mr. Chapman estimates the height of Pokono mountain above its base, at 850 feet; which, when compared with the foregoing elements, yields 1305 feet, for the elevation of that ridge, above the ocean.

Mauchchunk mountain, at the coalmine, is 1006 feet above the Lehigh at Mauchchunk village. We have seen, that the village stands 460 feet above the Atlantic level; therefore the justly celebrated coal mine is 1466 feet above the surface of the Atlantic. I may, however, remark, that some of the peaks of Mauchchunk mountain, between the mine and the village, must rise several hundred feet higher than the coal mine, and higher than the general elevation of the Kittatinny, as I have myself stood on two eminences of the Mauchchunk, and saw distinctly, the South mountain over the intervening Kittatinny. See Article NAVIGATION INLAND, page 384.

By recurrence to that article, it will be perceived, that I there estimated the elevation of the water level at the junction of Delaware and Lehigh, 200 feet above tide water; but subsequent, and more correct information, has induced me to diminish that estimate by one half. A discrepancy will be perceived, in some instances, in the respective river distances. This is, however, occasioned by sometimes using the comparative, or general, at others, the real length of the streams following the actual meanders.

We may safely assume, the general elevation of the cultivated part of Northampton, in the Kittatinny valley, from 250 to 350 feet; and for that section above the Kittatinny, a general elevation of from 500 to 600 feet. Mr. Chapman observes, that there is a difference in the seasons and vegetation of two weeks between the respective sections. The difference of elevation and exposure, exhibits the cause of this rapid change of temperature.

We will close this rather lengthy view of Northampton with a notice of its principal roads and towns.

A main turnpike road leaves Philadelphia, passes through Philadelphia, Montgomery, Bucks, and part of Lehigh counties; enters Northampton in the township of Lower Saucon, and crosses the Lehigh at Bethlehem. Here it branches into two routes. One turns north-west up the Lehigh, and passing by Kreiderville, through the Lehigh Water Gap, by Lehighton, Mauchchunk, and Lausanne, continues on to the banks of the Susquehannah, at Nescopec. From Bethlehem, the other, or northern branch, proceeds towards Easton, but breaks into numerous country roads, one of which leads on to Nazareth, and to the Delaware Wind Gap. The lower Philadelphia road reaches Easton, between the foregoing and Delaware river. Above Easton, a main road extends a little west of north, to the Wind Gap. Here it branches into two routes; one continuing north-west, to Wilkesbarre, and the other north, into Pike county. From Easton, another road leads up the Delaware to the Water Gap. Beside these, numerous good cross roads chequer the lower part of Northampton county, and render communication easy and convenient.

Northampton, contains the borough of Easton, and the villages of Bethlehem, Nazareth, and Richmond.

Easton, a post town and seat of justice, Northampton county, Pennsylvania, on the Delaware, 60 miles north from Philadelphia. It is a borough town, situated on a point of land formed by the Delaware and Lehigh rivers and Bushkill creek. The streets are laid out at right angles to each other, and along the cardinal points. The lower part of the town near the Delaware is on an elevated level, but the western extremity rises by a gradual acclivity to a considerable elevation. The adjacent country is bold, broken, and romantic. The soil is highly productive, and, being well cultivated, gives a most pleasing aspect to the vicinity of Easton. Farm houses, orchards, fields, and meadows, are comingled along the bottoms of the rivers and slopes of the adjacent hills. Bushkill creek is amongst the finest mill streams in the U. States. (See *Bushkill*.) The stream rises 8 miles N. from Nazareth, and has an almost uninterrupted fall to the Delaware. Within the borough of Easton it passes the Chesnut ridge, and by a very winding and precipitous course reaches the Delaware, affording a rapid succession of mill seats.

The following valuable information respecting this interesting place was communicated to the editor by an intelligent young gentleman, a native of that town. There are within the boundaries of the borough, 3 oil mills, 6 grist mills, 2 saw mills, 2 distilleries, 3 tan yards and tanneries, 1 brewery, and 31 dry good and hardware stores. A library formed in 1811, containing about 1200 volumes. An academy called the Union Academy, in which the learned languages are taught. Three places of public worship, 1 for Presbyterians, 1 for Episcopalians, and 1 for German Lutherans. A court house, erected in 1758. Four fine bridges; one over the Delaware, a most substantial structure, erected at an expense of 80,000 dollars; one a chain bridge, over the Lehigh, on the Philadelphia road, and two over the Bushkill. Two banks; one a branch of that of Pennsylvania, and the other the Easton bank, with a capital of 400,000 dollars. The trade of this town is very considerable, particularly in the article of flour, which constitutes the principal staple of Northampton county. Population in 1810, 1657, and in 1820, 2370.

Stroudsburg, a village and post town, on the north branch of Smithfield creek. It is built upon one street, and is the fourth in size in Northampton. An Academy has recently been established there. It is three miles north-west from the Delaware Water Gap.

Lehighton, a village situated on the west bank of the Lehigh river, about half a mile above the mouth of Mahoning creek. It is thirty-six miles west-north-west from Easton. Near this town stood the old Moravian settlement of *Gnaden Hutten*, on the north bank of the *Mahoning*, about 100 perches from its mouth, where the old *church* is still standing. Here a treaty of amity was held in July, 1752, between the Moravian brethren and the Shawanese Indians. Nearly opposite Gnaden Hutten, on the east side of the river, stood old Fort Allen. There is a wooden bridge across the Lehigh, 214 feet long, and 25 feet wide.

Berlinville, a village and post town, situated on the main road from Easton to Berwick, about two miles below the Lehigh Water Gap, and about one mile from the river. It is a small village, built upon one street, in Lehigh township.

Richmond, a village and post town, situate on the head of a small stream, to which it gives name, about two miles west of Delaware river. It is on the main road from Easton to the Delaware Water Gap, about sixteen miles from Easton, and about three miles west of Delaware river, in Upper Mount Bethel township.

Hellerstown, a post town, about the size of Stroudsburg, situated in Lower Saucon, near the extreme southern angle of the county, and four miles south-east from Bethlehem.

I have referred to the closing of the list of towns in Northampton county, a notice of Bethlehem and Nazareth.

Bethlehem, a post town of Northampton county, on the left bank of the Lehigh. East longitude from Washington City, 1° 46′. Lat. 40° 37′ N. twelve miles south-west by west from Easton. The United Brethren were settled here by Count Zinzindorf, in 1741. In 1800, the village contained 545 inhabitants, and the township 1343. In 1810, the township contained 1436; and in 1820, 1860 inhabitants, principally of the same sect.

The buildings are not remarkable for grandeur or elegance; but are generally comfortable. They have one house for public worship; a separate apartment for the residence of the single brethren; and another for the sisters. There is likewise a seminary for the education of young ladies, in which are taught, all the useful, and some of the ornamental branches of education. So great is the reputation of those schools, for the attention paid to the morals, as well as the literary improvement of the pupils, as to invite them from Philadelphia and other capital cities, and, indeed, from the most remote sections of the United States.

The scenery around Bethlehem, and the primitive manners of the inhabitants, give to the place an aspect of peculiar interest, in the eye of a traveller, and renders it eminently calculated to refine the taste, and preserve the morals of the students. It may be doubted, whether the world affords a more pleasing scene, than can be enjoyed, in a fine summer evening, in Bethlehem, when the groups of beautiful, and simply, though elegantly, dressed, and happy young females are let, loose from school.

It is the principal town of the Moravians, or, "*Unitas Fratrum*," in Pennsylvania. The site is very happily chosen; swelling with a gradual sweep, from the Monocacy creek and Lehigh river, which gives it a fine appearance, when viewed from the south or west, and preserves the streets dry and clean.

It is closely built in three streets. The principal one running north and south, and the other two, east and west.

The public buildings are, a large stone church, built in the Gothic style, and plaistered outside with a grey cement. It is 142 feet long, and 68 wide; with a proportionable height, and having a small tower rising from the centre of the top, surmounted with an elegant dome, in which is a small bell. It is handsomely furnished in the inside, having rows of benches on each side for the two sexes. A sister-house, or building for the unmarried women. A seminary for young ladies, where all the female Moravian children are educated, and also many others from various parts of the United States. The number now, 1822, about one hundred. A public tavern; being the only one permitted in the town, where, of course, all strangers are lodged.

Their burial ground is in the north-east part of the town, and is laid out in regular alleys and walks, planted with trees. The graves, contrary to the custom of other christians, are laid out with their feet to the south.

The number of dwelling-houses is above seventy, generally built of stone, one story high, forming a strong contrast to their large church. A fine wooden bridge crosses the Lehigh, and another the Monocacy.

Nazareth, another Moravian town, situated in Upper Nazareth township, on the head of a small branch of the Bush-Kill. Built principally on two streets, forming a right angle to the south and west. Its public buildings are, a church, and a seminary for boys; and here all the Moravian male children are educated, and generally a number of boys from abroad. The ground on which the town is built, descends to the south; houses generally of stone, and one story high; they are built close; and the streets have a paved walk on each side. This is, in magnitude, the third town in Northampton county. The village of Nazareth is the oldest settlement north of the South Mountain, in Pennsylvania. The Brethren having all first settled here, and afterwards removed to the river, where they built Bethlehem.

Nazareth is 10 miles north-east by north, from Bethlehem.

Population of Northampton county in 1810.*

Free white males,	19,475
do. do. females,	18,481
Total whites,	37,956
All other persons except Indians not taxed,	189
Slaves,	
Total population in 1810,	38,145

Population in 1820.

Free white males,	16,245
do. do. females,	15,320
All other persons except Indians not taxed,	
Total whites,	31,565
Free persons of colour, males,	109
do. do. females,	91
Slaves, males,	
do. females,	
Total population in 1820,	31,765

Of these:

Foreigners not naturalized,	198
Engaged in Agriculture,	5,787
do. in Manufactures,	2,398
do. in Commerce,	100

Population in 1820.

Townships.	
Allen,	1.847
Bethlehem,	1,860
Bushkill,	1,262
Chesnut Hill,	1,026
East Penn,	1,082
Easton, the Borough,	2,370
Forks,	1,659
Hanover,	358
Hamilton,	1,320
Lehigh,	1,550
Lausanne,	220
Lower Nazareth,	1,084
Lower Saucon,	2,208
Lower Mount Bethel,	2,472
Moore,	1,645
Plainfield,	1,127
Pokono,	389
Ross,	872
Stroud,	1,143
Smithfield,	961
Toamersing,	874
Upper Mount Bethel,	2,182
Upper Nazareth,	663
Williams,	1,590
	31,765

Staples of Northampton county, grain, flour, whiskey, fruit, cider, salted provisions, and coal.

NORTHAMPTON, a county of the Eastern Shore of Virginia; bounded by the Atlantic Ocean, east; Chesapeak bay, south and west; and Accomack, north; length 30, mean width eight; and area 240 square miles. Surface level, and soil sandy. It occupies the extreme part of the peninsula, on the east side of Chesapeake bay, from Cape Charles to the mouth of Pocomoke river. There is a Post-office at the Court-house.

Population in 1810.

Free white males,	1,615
do. do. females,	1,601
Total whites,	3,216
All other persons except Indians not taxed,	908
Slaves,	3,350
Total population in 1810.	7,474

Population in 1820.

Free white males,	1,629
do. do. females,	1,740
Total whites,	3,369
Free persons of colour, males,	440
do. do. females,	573
Slaves, males,	1,695
do. females,	1,628
Total population in 1820,	7,705

Of these:

Foreigners not naturalized,	13
Engaged in Agriculture,	1,876
do. in Manufactures,	103
do. in Commerce,	121
Population to the square mile,	32

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* At the census of 1810, Northampton county contained, what is now Lehigh, with the townships of Rush and West Penn in Schuylkill county.

NORTHAMPTON, a county of North-Carolina, bounded by Virginia, north; Hartford county, in North-Carolina, east; Bertie, south; and Roanoke river, or Halifax, south-west; length 40; mean width 12; and area 480 square miles. There is a Post-office at the Court-house.

Population in 1810.	
Free white males	2,600
do. do. females	2,644
Total whites	5,244
All other persons except Indians not taxed	580
Slaves	7,258
Total population in 1810	13,082
Population in 1820.	
Free white males	2,538
do. do. females	2,716
All other persons except Indians not taxed	
Total whites	5,254
Free persons of colour, males	363
do. do. females	362
Slaves, males	3,766
do. females	3,497
Total population in 1820	13,242
Of these:	
Foreigners not naturalized	1
Engaged in Agriculture	1,444
do. in Manufactures	111
do. in Commerce	9
Population to the square mile	27¾

Darby.

NORTHUMBERLAND, the most northerly county of England, is bounded on the south by Durham, on the west by Cumberland, on the north by the Scottish counties of Roxburgh and Berwick, on the east by the German Ocean. In shape it approaches to rhomboidal; the longest diagonal from south-west to north-east measures 74 miles, the shortest 45, the area amounts to 1871 square miles, or 1,197,440 acres. With regard to civil jurisdiction, it is divided into six wards, and 635 constableries; with regard to ecclesiastical, into 5 deaneries, and 73 parishes. It stands in the diocese of Durham; contains 12 market-towns; and sends 6 members to Parliament.

The face of the country is rugged and hilly; and the character of its scenery varies by many gradations from the extreme of wasteness to occasional beauty. On the northern side it is skirted by the Cheviots; and the mountains of Cumberland are connected with it on the west. From these wild and elevated ranges, numerous secondary branches traverse the interior in various directions; in some places spreading out into moory tracts of extreme desolateness, in others exhibiting a rich and well cultivated expanse, rendered more striking by its undulating and varied aspect. Along the summits of the mountains, which contain the numerous sources of its rivers, little else is to be seen than broad heaths, or cold and deep morasses: but as the streams grow broader, the sides of the hills gradually assume a greener hue, affording at first a more abundant pasturage for flocks, and at last separating into broad valleys, which often display all the luxuriance of vegetation.

In so great a diversity of position, we of course find a corresponding diversity of soil. On the highest elevations, it is cold, spongy, and irrecoverably barren; but the slopes of the mountains, particularly of the Cheviots, are of a firm consistency, and fertile, considering their situation. They are generally clothed with grass, and appear to have at one time been ploughed to a much greater height than at present. The finest districts are in the south, and along the coast from Bamborough to within some miles of the Tyne. The level tract around Belford, the uneven one in the neighbourhood of Wark, and the vale of Hexham, are distinguished for their beauty and productiveness. The harvests in this last quarter are the earliest, and its fields and woods have the richest verdure of any in Northumberland.

As the general exposure of this county is to the east, its climate is rather hard than otherwise. Cold, withering east winds prevail during the months of March, April, and frequently the greater part of May. When the western breezes set in, the progress of vegetation is rapid. It is not uncommon to see the trees in the beginning of May as arid and leafless as in December, and yet, through the influence of mild westerly winds and kind rains, becoming quite clothed with foliage in the course of eight or ten days. When these westerly breezes increase into a hurricane, it is a sure indication that a deluge of rain is falling at the time in the western counties of England and Scotland. The autumn of the year is the summer of Northumberland. During the months of September and October, it is usually fine settled weather; but winter commences by the middle of November, and reigns, with great severity, till the frost and snow are succeeded by a languid spring, in the latter end of March.

Of the Northumberland rivers, the Tyne is the most important. Its name in Celtic is said to signify *double*; and accordingly it springs from two sources, the South Tyne from behind Crossfell in Westmoreland, and the North Tyne from the borders of Scotland. The two streams unite beside Nether Warden; after which the river takes an easterly direction, and being joined by the Dill and the Derwent, empties itself into the sea between this county and Durham. The Till, the Aln, and the Coquet, much smaller streams, rise among the Cheviot hills. The two last flow directly into the German Ocean: the first mixes with the Tweed, which, during a considerable portion of its course, separates Northumberland from Berwickshire. Most of these rivers, by means of the tide and their natural depth, are navigable several miles above their mouths. Ships of large burden can ascend the Tyne to Newcastle, where its waters are deepened twelve feet every spring-tide. A few artificial helps might render the passage practicable much farther. In 1790, it was proposed to make the river navigable from Newburn to Hexham; but the corporation of Newcastle opposed the measure, and it was finally dropped. A similar fate has, from various causes, attended more than one succeeding project; and Northumberland is yet without any facilities for internal communication, except what are afforded by nature.

The sea-coast is generally steep, in some parts terminating in lofty cliffs of whinstone. Compared with the coasts farther to the south, it is reckoned safe and commodious. Adjacent to it are several islands, the principal of which are Coquet and Holy Island. Coquet lies opposite the mouth of the river so called, at the distance of about a mile. It was much frequented by monks in former times, and had a fortress on it, the ruins of which are now partly converted into a lighthouse. It abounds with rabbits, and contains seven acres of good pasture. Holy Island was once the seat of a monastery, which gloried in having been the residence of St. Cuthbert. It lies about two miles off the main land, from which it is accessible to carts at low water. It is nearly over against the mouth of the Lindis, a brook, from connection with which it was of old called Lindisfarne, the *recess* or retirement of the Lindis. The circuit of it measures nine miles; and includes 1020 acres, about half of which is sand, and stocked with rabbits. The remaining part, consisting of good soil, is now inclosed and cultivated. On the west side are, a small fishing town, and a castle garrisoned by a few soldiers from Berwick. In 1715, one Launcelot Errington seized it for a short time, in the name of the Pretender.

The fisheries on these islands, and along the coast, are limited in extent, and by no means productive. The rivers are more valuable in this respect. They yield excellent sport to the angler; and abound in salmon, which are caught in large quantities. In the Tyne, within half a century, two hundred and seventy-five salmon have been taken at a single draught. Owing to some works at Bywell, which obstruct their ascent, these fishes have now abandoned the Tyne; but the Tweed still affords above 8000 cwt. of them annually, for which there is paid in rents nearly 16,000*l.* The inferior streams afford a considerable supply also, and literally swarm with trouts.

But the grand source of wealth to Northumberland is the produce of its mines. Lead ore is found in great abundance on the western side of the county. The mines of Allenhead have been worked from time immemorial, and are still highly productive. The ore is found intermixed with calcareous or fluor spar; and the sides of the vein are often richly decorated with pyrites and yellow ores of copper. The whole mines of this district annually give about 12,000 bings, or nearly 5000 tons of ore. It is smelted and refined at Dukesfield; and produces about seven or eight ounces of silver from each fother of lead. Mines of lead are also worked in the vicinities of Corbridge and of Bamborough; some others formerly existed at Stonecroft and in Rothbury forest. The lead veins usually contain ores of zinc in great abundance: and large quantities of iron-stone are inclosed in the strata of indurated clay throughout all the coal districts.

The iron-stone found here is not now prepared to any extent within the county; but the accompanying mineral, the pit coal, has long formed the staple commodity of Northumberland. This valuable substance occurs in immense beds, dispersed under a surface of about 300 square miles, the principal part of which lies within a triangle, having Tynemouth, Bywell, and Alnemouth at its corners. This tract, so far as it has been pierced into, is found to consist of various kinds of siliceous stone, schistus, and coal. Beds of schistus usually lie both above and beneath the coal-seams, and are often thickly impressed with vegetable forms, such as ferns, vetches, and grasses; in some cases ears of barley and leaves of pine-apples have been noticed. In these beds are also found layers of iron-stones, sometimes in nodules; more frequently in rhomboids, having the corners rounded off. Sometimes large trees are found, extending out of the clay into the stone strata: At Kenton are some seats of stone, hewn from one of those remarkable fossils, that show the yearly rings of the tree, and the roughness of its bark. Sometimes the wood is half carbonated, like the *surturbrand* of Iceland.

In this, as in every coal district, the stratification which attends the fossil always terminates, and is ill-defined and disordered, when it approaches any mountain of porphyry or granite. The strata generally dip towards the east; and each stratum usually retains its parallelism, with regard to those immediately above and below it, through all the confusion of those perpendicular rents and chasms, which, in mining language, are termed *dikes*, *slips*, *hitches*, and *troubles*. Some of those chasms are filled up with substances swept into them, as it would seem, from the surface, such as clay, sand, and round stones. Some of them contain metals and beautiful spars; others are composed of basalt. The basalt dike in the coal-mine at Walker is noted among mineralogists for being cased with cinders on each side.

Out of those mines, some of which are 280 yards deep, the fossil is extracted by many ingenious contrivances, wherein the labour has, in later times, been greatly diminished by the application of steam-engines, which are now in universal use, the first having been set up in the year 1714. The coals are conveyed in railways to the water,—by much the larger portion of them to the Tyne, where they are taken on ship-board, and transported to London and all other quarters of the empire. They are reckoned superior to every other species; and even in districts where similar minerals abound most plentifully, it is customary for the people to procure a portion of Newcastle coals to mix with their own. In the neighbourhood of limestone strata, a kind of coal is found, which, though comparatively useless in other respects, is employed for burning the attendant mineral, and excellently adapted for that purpose.

Some indications seem to favour the conjecture that coal-mines were worked by the Romans, and even by the Britons. Coal is mentioned as a well-known species of fuel, in a grant dated A. D. 852, by which it is stipulated that twelve cart-loads of that fossil were to be paid yearly to the Abbey of Peterborough. It seems, however, to have fallen again into disuse; for no mention occurs of it till the beginning of the thirteenth century, when a charter was given to Newcastle, by Henry III., allowing liberty "to dig coals and stones on the common soil of that town, without the walls thereof, in a place called the Castle-field and the Forth." This was in 1239. Soon afterwards the use of it began to extend from the forge to the kitchen: it has ever since continued to increase. In the latter end of Queen Elizabeth's reign, a duty of fourpence per chaldron produced 10,000*l.* a-year. Above 400 ships were constantly employed in the trade; a fleet of fifty sail went laden from Newcastle to different ports of France; while the Dutch and Danes supplied those of Flanders. The unpopularity of Charles I. in London was greatly augmented by the taxes he imposed on this trade, and the monopolies he authorized in it. When the Scottish armies took Newcastle, the regulations of the Parliament lowered the price of coals greatly beneath the 4*l.* per chaldron, to which it had once risen: but the trade did not prosper under them. Still, however, the consumption of the article continued to diffuse itself. In 1699, Newcastle had two-thirds of the coal trade, and 300,000 chaldrons went annually to London. The over-sea trade employed about 900,000 tons of shipping. In the whole trade were employed 600 vessels, of the average burden of 80 Newcastle chaldrons, manned by 4500 sailors. On the Tyne, also, were employed 400 keels, and nearly 16 000 keelmen. The inventions of Bolton and Watt, as well as the general improvement of the country, gave fresh vigour to the trade in coals. From the first of January, 1802, to the end of December, 1809, it appears that 4.713,476 chaldrons, or 12,490,707 tons, were exported from the Tyne alone.

The mineral wealth of Northumberland, and the trade occasioned thereby, have exerted a beneficial influence on its agriculture. For a soil and climate in general so little favourable, farming is carried on with industry and spirit, and the produce is considerable. Notwithstanding its vast tracts of moory land, the annual value of a square mile, on the average, amounts to 520*l.* Landed property is a good deal subdivided: the rental of estates varies from the smallest sums to above 30,000*l.*; in one instance it exceeds 80,000*l.* Towards the sources of the Tyne, and in some other mountainous districts, the ground is parcelled into lots, worth from 30*l.* to 300*l.* a year, which are commonly farmed by their proprietors. As those *statesmen* have in general received their property through a long succession of generations, they are apt to show a strong attachment to the useless as well as to the useful, in ancient customs: they admire and imitate the honest, though rude independence of their fathers; and give small countenance to innovation, whether it be improvement or the contrary. Farms are not less various in extent than estates are. In the southern and midland parts of the county, the rent is often from 50*l.* to 300*l.*: in the wards of Glendale and Bamborough, it is from 2000*l.* to 4000*l.*

In such a diversity of circumstances, no one system of husbandry can be expected to prevail universally. On dry lands it is customary to adopt this rotation: turnips, barley, or wheat; clover for one or two years; oats, or wheat, if barley was grown previously. On strong loams, the usual course is, fallow, wheat, clover, for one or two years; beans or oats. On moist thin loams, fallow, wheat, clover; grass-seeds for one or two years. And upon moory soils, fallow, oats, clover; grass-seeds for two years. Some intelligent farmers in the north maintain that a course of three years tillage, and three years grass, is a much more profitable system than any other they have tried. Drill-sowing is generally preferred to broad cast; and excellent manure, abounding over all the county, is copiously applied. Lime is found in almost every quarter, except in the porphyry districts of the Cheviots, and some of the coal-fields in the south. Both stone-marle and shell-marle are likewise extensively diffused; sea-weeds, collected from the rocks, or washed ashore by the waves during the fall, are eagerly collected along the coast; and a considerable supply of manure is annually brought from London, as ballast, by the ships employed in the coal trade.

The rearing of cattle is considerably attended to, particularly in the upland districts of the county. The cow is usually of the breed called Dutch; it grows rapidly; at the the age of three years and a half, the carcass, when fattened, will weigh from 60 to 80 stones. Sheep are produced in much greater numbers; they form a prominent department in the stock of corn-farms, or range over large moory tracts, which, though mostly the property of private individuals, are seldom inclosed, or separated otherwise than by streams, ridges of hills, and other natural boundaries. The most common sorts are the Cheviot sheep, a beautiful breed, which weigh, when fattened, from 12 to 18 pounds per qurrter; the heath sheep, which are reckoned fittest for living on the mountains, and afford an excellently flavoured kind of mutton, weighing about 18 pounds in the quarter; and the long woolled or Dishly sheep, which are preferred in less elevated situations, being remarkable for fattening at a very early age. These last are said to have been greatly improved here, by ingenious management; the carcass weighs from 18 to 26 pounds per quarter; the fleece about seven and a half.

The exportation of its agricultural products gives employment to a few Northumberland ships, besides what are employed in the coal trade, the nature of which has already been described. As the exports of the country are mostly in a raw state; as coals, its greatest export, in addition to this, are very bulky; the outward bound cargo is, of course, much more considerable than the inward. The intercourse is chiefly with the ports along the adjoining coast, and a few places on the Continent. The grain and the salted provisions prepared within the county, its vessels carry out to various British harbours; they bring in Baltic or colonial goods, and most of the manufactured articles which are consumed between the interior mountains and the sea. Newcastle sends three or four ships to the Greenland fishery. The internal manufactures are of no great extent, and little diffused over the county. Glass is the most prominent of them. It was introduced at Newcastle in 1619; at present there are 28 glass-houses on the Tyne; the duties levied on them amount to nearly 200,000*l.* a-year. Small potteries and founderies exist, likewise, in several quarters; and some establishments for working in gold and silver distinguish the county town.

According to the parliamentary returns, Northumberland, with the town of Berwick, in 1801, contained 26,518 houses, and a population of 157,091, whereof 23,190 were employed in agriculture, and 25,738 in trade and manufactures. In 1811, the number of houses was 28,258; the population 172,561; the number of families employed in agriculture being 10,945, and in trade and manufactures 16,547.

See *Beauties of England and Wales*, vol. xii. part first.

NORTHUMBERLAND, a county of Pennsylvania; bounded by Schuylkill, south-east; Dauphin, south; Susquehannah river, or Union, west; Lycoming, north, and Columbia north-east; length, 35; mean width, 13; and area, 455 square miles. This is one of the mountain counties of Pennsylvania, and very much diversified in surface. Having so much river land, it possesses, notwithstanding its general mountainous aspect, a large proportion of good, and considerable first-rate soil. Washed by the main Susquehanna, 20 miles below, and by the west branch, 20 miles above Sunbury and Northumberland, produces a range of river soil of 40 miles in length. To this may be added 10 miles of the east branch, between Sunbury and Danville; the whole, including both banks of the latter section, yielding a river line of 60 miles. This alluvial range contains the mass of the population.

Contrary to the ordinary course of the Appalachian ridges, the mountains of Northumberland extend nearly east and west. The principal ridges are, advancing from south to north, Line Mountain, Little Mahanoy, Mahanoy, and Shamokin, below the junction of the two great branches of Susquehanna: above their confluence, Montours Mountain, and the Limestone Ridge.

Beside the two fine rivers we have noticed, Northumberland is drained by some large creeks, the principal of which are, Mahantango, Mahanoy, and Shamokin, entering Susquehanna, below Sunbury; and Chilisquaque, Limestone, and Warrior creeks, above Northumberland. Some of those creeks meander through narrow valleys, with much good soil.

The staple productions of Northumberland, are grain, flour, salted provisions, lumber, whiskey, and many other articles.

Its principal towns are, Sunbury, Northumberland, Milton, and Watsonburg.

Sunbury, a post town, borough, and seat of justice, stands on the left bank of Susquehanna river, immediately below the main fork, and above the mouth of Shamokin creek.

Northumberland, a post town, stands on the point above, the junction of the two main branches of Susquehanna, and opposite to Sunbury.

Milton, a post town and borough, is situated on the west branch of Susquehanna, 12 miles above Northumberland.

There are some other villages in the county, but undeserving particular notice. The two following tables exhibit the aggregate, and relative population of this county.

Population in 1810.

Free white males - - - - - - - - -	18,673
do. do. females - - - - - - - -	17,457
Total whites - - - - - - - - - -	36,130
All other persons except Indians not taxed	194
Slaves - - - - - - - - - - - -	3
Total population in 1810 - - - - - -	36,327

Population in 1820.

Free white males - - - - - - - -	7,773
do. do. females - - - - - - -	7,537
All other persons except Indians not taxed	
Total whites - - - - - - - - - -	15,310
Free persons of colour, males - - - -	59
do. do. females, - - -	54
Slaves, males - - - - - - - - - -	
do. females - - - - - - - - - -	1
Total population in 1820 - - - - - - -	15,424
Of these:	
Foreigners not naturalized - - - - -	53
Engaged in Agriculture - - - - - - -	1,350
do. in Manufactures - - - - -	29
do. in Commerce - - - - - -	665
Population to the square mile, nearly - -	34

Population in 1820.

Townships.	
Upper Mahanoy - - - - - - - - - -	1,639
Lower Mahanoy - - - - - - - - -	1,214
Augusta - - - - - - - - - - -	2,075
Chilisquake - - - - - - - - - - -	1,035
Little Mahanoy - - - - - - - - - -	447
Milton, the Borough - - - - - - - -	1,016
	7,426
brought forward,	7,426
Point - - - - - - - - - - - - - -	1,373
Rush - - - - - - - - - - - - - -	1,192
Sunbury, the Borough - - - - - - -	861
Shamokin - - - - - - - - - - - -	1,820
Turbut - - - - - - - - - - - - -	2,752
	15,424

NORTHUMBERLAND, a county of Virginia; bounded by Potomac river, north-east; Chesapeak bay, south-east; Lancaster and Richmond, south-west; and Westmoreland, north-west; length 30; mean width 8; and area 240 square miles. Surface rather waving than hilly. Soil of middling quality. Chief town, Bridgetown.

Population in 1810.

Free white males - - - - - - - - -	2,005
do. do. females - - - - - - - -	2,157
Total whites - - - - - - - - - -	4,162
All other persons except Indians not taxed	299
Slaves - - - - - - - - - - - -	3,847
Total population in 1810 - - - - - -	8,308

Population in 1820.

Free white males - - - - - - - - -	2,087
do. do. females - - - - - - - -	2,047
All other persons except Indians not taxed	
Total whites - - - - - - - - - -	4,134
Free persons of colour, males - - - -	320
do. do. females - - -	294
Slaves, males - - - - - - - - - -	1,651
do. females - - - - - - - - -	1,617
Total population in 1820 - - - - - -	8,016
Of these;	
Foreigners not naturalized - - - - -	2
Engaged in Agriculture - - - - - - -	2,426
do. in Manufactures - - - - -	108
do. in Commerce - - - - - -	18
Population to the square mile - - - -	33

DARBY.

NORTHWICH, a town of England, in Cheshire, is situated near the conflux of the Dane and the Wever. The streets are irregular, and the houses in general old. The church, which is a spacious building, has a fine semicircular choir. The principal manufactures are cotton and silk. Population 1338.—See CHESHIRE, and SALT, to the end of the article.

NORWAY, the most interesting, but the least known, of all the countries comprised in the ancient Scandinavia, is situated between the 57th and 71st degrees of north latitude, and between 5° 20′ and 18° 20′ of east longitude from Greenwich. It extends about 950 miles from north to south. Its breadth, in the southern provinces, is between 150 and 240 miles; but, beyond the 67th of north latitude, does not exceed 60, nor in some places even 30 miles. It is bounded on the south by the Scaggerac Sea, on the north and west by the Northern Ocean; and on the east by Russian Lapland and Sweden. On the side of Russian Lapland, the limits are very uncertain; but from Sweden it is separated, for the space of 350 miles, by a chain of lofty mountains, which form a natural frontier to the two kingdoms, and which was more precisely delineated by a treaty between the two governments in 1751.

Norway is distributed into four governments, Christiania, or Aggerhuus, in the south-east, the richest and most populous province in the kingdom. Christiansand, or Stawanger, in the south-west, a fertile and well-watered tract, but scarcely half so extensive as the former; Bergen, a rugged and barren territory, stretching along the western coast nearly 200 miles; and Drontheim, the most northerly of all, a long narrow mountainous region, covered by a broken and dangerous shore. The first of these contains the provinces of Aggerhuus, Hedemarken, Christian, Buskerud, Smolehnene, Bradsberg, Laurvig, Jarlsberg; and its principal towns are Christiania, Kongsberg, Friederickshald, Bragernass, and Stromsoe. The second contains the provinces of Nedenas, Mandal, Stavanger; and its principal towns are Christiansand, Stavanger, and Arendal. The third contains the provinces of Sondre Bergenhuus, and Noorde Bergenhuus; and its principal towns are Bergen, Vossevang, Evindvig, Ous, Kinservig, Lindoos, and Manger. The fourth contains the provinces of Drontheim, Romdal, Nordland, and Finmark; and its principal towns are Drontheim, and Christiansand.

The mountains of Norway generally stretch in continued chains of considerable extent, chiefly from north to south, though sometimes from east to west, but occasionally appear in separate masses, and in the most fantastic forms. The most elevated of these ridges is that of Duvrefieldt,* nearly in the centre of the kingdom, between 62° and 65° of north latitude, and forming a part of the immense chain which separates Norway from Sweden. The highest of this groop is Sneehattan, the summit of which was reached, for the first time, in 1797, by M. Esmark, who ascertained its height to be about 8115 English feet. From Dovrefieldt, a long branch, decreasing in elevation as it proceeds, stretches northward between Norway and Swedish Lapland, forming at its farthest extremity the mountains of Kiolen. Another branch, from the same central point, extends to the south-east, forming the common boundary between Norway and Sweden, and is sometimes called Seveberg, which is again subdivided into the ridges of Butefieldt, Sulefieldt, and Skarsfieldt. A third branch, called Langfieldt, proceeds westward and then southward towards the Naze, dividing Norway into two principal regions, Sondenfieldts and Nordenfieldts. Several of these lofty summits are real *glaciers*, covered with perpetual snow and ice: but these are not always either the most elevated or the most northerly. Immense avalanches, sometimes dragging with them masses of rock, are frequently precipitated from these mountainous ridges into the plains and valleys; and, besides the immediate devastation produced by their fall, they often occasion the most destructive inundations, by interrupting the course of the rivers, or causing an overflow of the lakes. The mountains along the coast are remarkably rocky in their surface, and varied in their forms. Those of the interior are less barren, but usually destitute of all vegetation on their summits.

The greater part of the principal chains are composed of primitive and transition rocks; and granite, contrary to the general belief, is now found to occur very rarely in Norway and Lapland. Gneiss appears to be the most abundant of all the primitive rocks, and to it the others are generally subordinate. The class of transition rocks in Norway contain grey-wacke, alum-slate, clay-slate, granite, syenite, porphyry, amygdaloid, basalt, and sand-stone. There are numerous quarries of slate and marble, and great varieties of crystals; but flint is scarcely found, and free-stone is rare. There is little gold; but the silver mines, particularly at Kongsoerg near Christiania, have been very productive. There are valuable mines of cobalt at Fossum, of copper at Roras, and of iron at Christiania. Lead has been found, and alum works established; and altogether there are said to be† 8000 mines in Norway; but no coal has yet been found there. Great beds of blue marly-clay, full of shells of different kinds, are discovered in various quarters, and at considerable elevations. There are multitudes of clear and fresh springs in the country, very commonly tinctured by iron; and in some districts there are mineral waters, properly so called, but their qualities are little known, and seldom is any use made of them.

The waters from the mountains of Norway give rise to a multitude of rivers and lakes. A great many of the former originate in the Dovrefieldt. Those which flow towards the northern division, the Namsen, Gula, Orkedal, Tana, Alten, are least extensive in their course, and soon reach the coast. But those which pass through the southern provinces are of greater volume, such as the Nidel, Mandalselv, Darmmenelv, Loven, Fœmund, Laugen and Glommen. The last is the principal river in Norway. It originates in the lake Oresund, under the 62° of north latitude, and runs southward about 90 miles, through a rugged channel full of cataracts and shoals. Before it receives the Worm, (lake Mioss,) it is as large as the Thames at Putney: and about 20 miles below this junction falls into the sea at Frederickstadt. Its highest cataract is that of Sarpen, above 60 feet perpendicular, and not far from its influx into the sea. The greater part of these rivers have falls more or less considerable, and are not fitted for regular navigation, except for the floating of timber down the stream. They often occasion great devastation by overflowing their banks, of which a remarkable instance occurred in the year 1789, after a long continuance of rain, which caused a general inundation, and produced the most serious ravages over the greater part of the kingdom. These rivers, nevertheless, afford many advantages, by the inland though interrupted navigation which they admit; by the multitude of saw-mils which they put in motion; by the abundance of excellent fish which they supply; and by the fertility which they communicate to the valleys through which they flow.

The lakes of Norway are extremely numerous; and some of them of considerable extent, particularly those which are situated in the southern provinces. Besides Sneaasen, Foelboe, Rysvandet, Sperillen, there are the lake of Tyri, about 15 miles in length, surrounded by fine meadows and corn-fields; that of Fœmund, about

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* Fiel in the Swedish, and fieldt in the Norwegian language, properly denotes those elevated summits, where vegetation entirely ceases; but is a common denomination for all lofty mountainous ridges.

† The copper mines are generally situated in the northern, and the iron mines in the southern provinces.

30 miles long and 6 in breadth, inclosed by mountains of great height; that of Rands, nearly 40 miles long, but only two broad; and that of Mioss, about 70 Enlish miles long, and 12 in breadth, near the middle of its extent.

The coast, though in some places low, and rising gradually, is in general bold and steep, with a depth of water, often close to the rock, of from 100 to 400 fathoms. Along the western shore there are numerous islets and rocks, which form a kind of break-water to the coast, and furnish a number of secure harbours and places of retreat for vessels in stormy weather. There are numerous creeks or gulfs, which run far into the land, sometimes to the extent of 30 or 40 miles; and occasionally pass out in such a manner as to form straits. Those towards the north are seldom frozen; an exemption which is supposed to be owing to the constant agitation of their waters by the rapid rivers and torrents which fall into them. The most remarkable of these creeks or fiords are those of Christiania, Stawanger, Hardanger, Segnifiord and Drontheim. It is in these arms of the sea that the principal ports are situated, and the most important fisheries carried on. There are many dangerous currents along the western coast, the most noted of which is that of Malstroem or Moskœstroem, in latitude 67° 40′. It runs among several islands with extraordinary rapidity during six hours from north to south; and during other six hours from south to north, always against the tide; but at high and low water is stationary and navigable. During the periods of its agitation, it is necessary for vessels to keep at the distance of several miles, lest they should be drawn into its current; and frequently whales which approach too near are overwhelmed and destroyed by the irresistible force of its waters. When a strong wind blows in from the west, and opposes these currents, the most frightful waves are excited, and the roaring of the contest is heard at an immense distance; but it is only during the storm of winter that these violent agitations are witnessed; and the stream is generally navigable in the summer months.

The climate of Norway is by no means uniform, but varies, of course, in proportion to the latitude and the elevation of different places. When the summits and sides of the mountains are already under the influence of winter, the valleys frequently enjoy a high degree of temperature; and along the west coast, the cold is not nearly so intense in the same latitude as in the mountainous line on the east frontier. At the southern extremity the cold is seldom rigorous, rarely below the 18th of Reaumur; but in Finmarken it reaches such a degree of severity, that all vegetation seems to expire under its power. At Christiania, the winter is not much earlier than in the north of Germany; frost is very rare in November, and the snow seldom lying till the beginning of December. From the end of April, the warmth increases very rapidly, and in general the spring is so short, that the winter seems to be immediately succeeded by summer. On the 5th of May 1808, the thermometer at Christiania rose to 70° of Fahrenheit; and in the middle of the month all the trees except the ash were in leaf. The mean temperature of July was 65, and the thermometer at noon was generally 81, or sometimes even 86 degrees. But in summer the weather is very unsteady, one day being extremely hot, and the next quite cold; sometimes these transitions take place in the course of a single hour. The harvest commenced before the beginning of August; but before the end of September stoves were become necessary in the town. But at Saltenfiord, the mean temperature is scarcely above 34° of Fahrenheit, and the highest in the month of July 57° 8′. It is a prevailing opinion throughout the country, that the climate is preceptibly changing, both on the sea-coast and in the inland valleys; that the summers are not so warm; the winters less cold, though more tedious; and the spring, which scarcely existed as a distinct season, now considerably prolonged. Nor do the inhabitants draw such conclusions from their own sensations or recollections, but from such facts as these: that, at Drontheim, where fruit was formerly raised, there has been none for a long time past; that at Hardanger there are incipient glaciers daily increasing, of which there was not the slightest trace a few years ago; that at Sandtorp, those points of the mainland which used to be free of snow every summer have never lost it for several years. At Bergin, the longest day is nineteen hours, the sun rising at half-past two o'clock, and setting at half-past nine; and the shortest day six hours, from sun-rise at nine o'clock to sun-set about three. Beyond Bergen the sun remains still longer above the horizon during a part of the year; but during another period it is scarcely at all visible. At the extremity of Nordland, and in Finmark, it does not appear for several weeks in the winter season; and the day is little more than a kind of twilight of an hour and a half, which the reflection from the high mountains occasions; but the *aurora borealis*, which is remarkable for its beauty and brilliancy in those regions, and the whiteness of the snow, contribute in a great measure to dissipate the darkness. At the longest days, there are few places in the more northern districts where the sun is really always apparent above the horizon; but some rock or mountain frequently interposes to hide it for several hours during the night; and sometimes this will happen more than once. At these obscurations the temperature falls, and does not rise again till above an hour after the sun's reappearance; so that, in these cases, there are apparant settings and risings of the sun, though it is never in reality below the horizon. The most violent winds in Norway are the south-east and north-west, which bring with them rain and tremendous storms. Those from the north and north-east bring dry weather, and purify the atmosphere. This dry weather prevails most during the months of March and July, rain in October and April, and* snow in December and January. The months of May, April, and October, are the most stormy; and those of January, June, and August, the most favoured with calm weather. Thunder is seldom heard, and in some districts is wholly unknown. Hail is very rare, and always in very small particles. A singular circumstance is observable along the western coast, viz. that in summer, after a storm of wind during the day, there is almost invariably a calm in the evening, and for several hours of the night; but in winter, on the contrary, it is always during the night that the blasts become most violent, and occasion the greatest damage. The air of Norway is remarkably pure, and the climate, though severe, is highly favourable to health and longevity. In some of the western districts, a contagious malady, named radesyge, is very frequent, resembling in its symptons those of the scurvy and lues venerea, and which is supposed to be owing to the use of a fish diet, and the humid situation of the houses. In medicine they make much use of the lichen islandicus, which is found upon all their mountains; but their favourite remedy is camphor, which they administer in all disorders, and which they find most effectual in curing colds.

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* The want of snow is considered as a serious privation, as in winter, which is the season of business, all intercourse is carried on by means of sledges.

"It is the peculiar characteristic of the Norwegian mountains to combine the grandeur of Alpine scenery with the dark solemnity of the groves of Sweden, and the luxuriant softness of the vales of Italy."[*] The verdure in the Norway valleys is peculiarly soft, the foliage of the trees luxuriant, and in the summer season no traces appear of a northern climate. In Guldbrandsdale, for a distance of 170 English miles, along the banks of the river Louven, there is a succession of the finest landscapes in the world. The views around Drontheim are accounted equal to those of the bay of Naples itself; and altogether Norway has been pronounced by travellers most competent to judge, to be a country more worth seeing by the lovers of picturesque beauty than any other in the world. Among the most remarkable objects in these scenes are, the farm-houses, which seem to hang upon cultivated spots one above another, till they reach the clouds, cattle, corn-sheaves, and labourers appearing actually above the clouds in places seemingly inaccessible. These elevated situations are preferred for this reason, that the higher the land is, the more sun it receives.

Norway is so full of rocks and mountains, interspersed with deep morasses and barren wastes, that it possesses a very small portion of soil capable of cultivation. There are many valleys, some of which are extremely narrow, others of wider extent, and a few so well opened as to resemble plains, particularly Jeddeeren and Hedemarken. The high valleys are chiefly used for pasture, and the lower for tillage. The southern coast is, upon the whole, the most fertile, and, in some low tracts, clay and sand prevail. In the higher grounds, the rocky bottom is covered by a thin bed of mould, produced by the decomposition of vegetable substances. On the clay-slate, the soil yields twelve times the amount of the seed, but on the rocky gneiss bottom, it hardly repays the labour bestowed on its cultivation.

The natural productions of the country are very numerous, and many of them serve the most useful purposes. Lichens of various kinds are very abundant; and, besides supplying food for the cattle, are collected and sold for purposes of dyeing. There are several medicinal herbs, such as angelica, veronica, gentian, cochlearia, which the inhabitants gather and use as remedies. Cumin frequently covers extensive tracts, and is collected in immense quantities. Nettles are abundant, and are made into thread, or sometimes used as food like spinage. The barberry and sloe are plentiful; the former of which is often used as a pickle, and the latter made to yield a sort of wine. The wild rose is often seen among the rocky spots, and its fruit is employed in different preparations for the table. Juniper berries are collected carefully, and sold to the Dutch. Strawberries, raspberries, and several other kinds of berries peculiar to northern countries, are sufficiently abundant. Trees form a prominent feature in Norwegian vegetation, and often grow to a great size of timber. In the southern districts are found the oak, beech, elm, and linden trees; sycamores, alders, aspens, hazels, and willows. Pines and Scotch firs are spread over the greatest extent, and form a considerable part of the wealth of the country. The birch also is found in most quarters, even of the northern regions, and is applied to a great variety of useful purposes. The outer bark is used as a covering for the houses, or is made to yield an oil for tanning leather; the inner bark is wrought into nets or baskets. Its wood furnishes the best ashes and charcoal; and, in the spring, a pleasant acid liquor is drawn from the tree, and made into wine. Fruit trees are found wherever the oak will grow, which is only at a mean temperature of 40° of Fahrenheit. At Christiania, under the 60th degree of latitude, apples, cherries, pears, and apricots, grow in the open air; but at Drontheim, under 63° 30′, apples ripen with difficulty; and no other fruit will come to maturity, although in some favoured spots, even farther north, cherries are raised, and oaks, lime, and ash, are to be seen. Dr. Clarke, however, saw at Drontheim, in the year 1799, apples, pears, plums, and cherries; and strawberries were gathered that season on the 20th day of June. All sorts of garden vegetables are now common in this northern city, cabbages, cauliflowers, turnips, cucumbers, potatoes, artichokes; and even pinks, carnations, roses, stocks, and many other garden flowers, were observed in the garden. Formerly, the towns and cities of Norway were supplied with culinary herbs from England and Holland; but their recent attention to gardening has rendered this supply unnecessary.[†]

The rapidity of vegetation on some spots, and in some years, is very extraordinary. Even to the north of Drontheim, two crops of barley have been reaped in the same year; and it is no uncommon occurrence for this kind of grain to be reaped six weeks after it has been sown.

Agriculture in Norway, though practised from a very remote period, has made little progress, in proportion to the wants of the nation; yet in some districts, the industry and exertions of the peasantry to overcome the natural obstacles with which they have to contend, are truly extraordinary, and deservedly successful. The rocky mountains which cover so large a portion of the country, and preclude all sort of tillage; the rapid torrents which rush down from the heights, sweeping away the produce and the soil together; the short duration and variable nature of the season favourable to vegetation; and even the parching heat of the summer sun reflected among the rocks around the valleys; all present the most serious difficulties and discouragements to the labours of the husbandman. Notwithstanding all these obstacles, the inhabitants of Norway, by careful attention, and judicious management, have done much to overcome their natural disadvantages; and might carry their activity and skill to much greater lengths, were they better protected by the civil regulations of their country. Though personally free, and seldom subjected to any services of vassalage, yet they are greatly harassed by the burden of military service, and of furnishing conveyances to public functionaries, as well as fettered by restrictions from extending their farms and undertakings. A considerable obstruction to agriculture arises from the timber merchants, who buy large tracts of woods from the farmers, who reserve in these sales the right of pasturage for their cattle, and of cutting timber for their houses and fuel; but who are not at liberty to build an additional dwelling, and to take in a new piece of ground for cultivation, without leave from the proprietor of the woods, confirmed by the magistrate of the district, declaring that the spot is not fit for timber. They have recently, however, received considerable countenance from patriotic societies for the encouragement of agriculture; and, by their own native enterprise, have accomplished many valuable improvements. In most places, which are at all favourable for agriculture, are to be seen clean and neatly built farm-houses, many of which are two stories high; gardens around them full of turnips, hops, potatoes and other roots; fields enclosed with hedges, and carefully cleaned. Often are these establishments observed upon an arid ridge, and crops rising among frightful rocks, or verdant meadows in the bosom of a black forest. Among numerous contrivances to counteract the evils of their climate, they make small hedges behind each other along the declivities, to retard the snow from melting too suddenly, and rushing down in torrents; and in the dry month of June, when the sunshine is bright and uninterrupted, water is brought from great distances, and distributed over the parched fields of grain; while in harvest they are obliged to place new hurdles among the standing corn, to prevent it from being laid by the heavy winds and rains. Yet often in the end of summer, or during the autumn, a premature frost destroys the grain in the ear, and disappoints all their hopes. In the south of Norway, agriculture succeeds best; and, in good years, enough of grain is produced in that part of the country to supply its own wants, with the addition of a small overplus for the use of the northern districts. The best cultivated and most productive districts are, Hedemarken, Hadeland, Toten, Romerige, and Ringerige, in the government of Christiania; Vos and Sognedal in that of Bergen; Jederen, Ryfylke, and Nedeness, in that of Christiansand; and Nommedal and Inderkerred in that of Drontheim. Oats are the most generally cultivated in Norway; barley and rye hold the next rank; but wheat, buck-wheat, and peas, are far from being common. In the mountainous tracts, the oats and barley are usually sown in the months of April and May, that the harvest may be finished before the arrival of the cold nights of the autumn; but on the coast they are seldom sown till June. The grain is generally cut about the end of August or beginning of September; and sometimes rye, which has been sown in the preceding autumn, is ripe in the month of July. Potatoes have been generally introduced into cultivation, but do not attain a sufficient size during the short summer of the country. Since their introduction, less attention has been paid to the culture of a species of turnip, which was much used as food. There is great want of manure in the arable tracts; and the nature of the soil will not admit of a proper rotation of crops. Clover has been introduced, but is not generally raised. Hemp is grown in some districts, and a little tobacco. It has been an old practice in Norwegian husbandry, (though now prohibited, unless permission has been procured from the public authorities,) to cut down a few acres of wood, and set fire to the trees, after which the seed is sown among the ashes, and great returns procured. Next year the remaining trunks, which had not been consumed, are in like manner reduced to ashes, and a new crop sown. The soil is then left to itself, or usually sends up bushes of birch.

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[*] Clarke.

[†] In the year 1819, the finest apricots were gathered in August, and peaches in September, from trees in the open air at Mioss.

Gardening has made considerable progress in the south, and even in some of the northern provinces. Various kinds of pulse, onions, pot-herbs, and different roots, succeed well; and besides the fruit trees already mentioned, several wealthy proprietors have hot-beds and green-houses.

One of the most valuable productions for the support of cattle, which is also used as food by the natives, (though in some measure supplanted in this view by the potatoe,) is the turnip, called Kale Raby. It is of a yellow colour, has an agreeable flavour even in its raw state, affords a delicious vegetable dish when boiled for the table, and grows to a very large size. The green leaves of it, which resemble those of a cabbage, are the most profitable part as fodder for the cattle, the outer leaves being taken off so as not to injure the heart, and sprouting again, supply an abundant crop. This turnip is sown in good garden soil in the spring, and transplanted in the month of June into good soil without manure, four plants being set in every square of three feet. Thirty-five English square yards will yield in good years 30 Norway tons, or 20 English quarters of this produce.

Every farm has a certain number of married labourers employed on it in proportion to its extent, who are called house-men, as they receive from the farmer a house and a quantity of land nearly sufficient to maintain a family; in return for which they are bound to work for him at a low and fixed price, whenever they are called. Except in the neighbourhood of towns or of the coast, a young Norwegian cannot marry till he has a place of this kind open for him, as he could not find employment for more than three or four months in summer; and hence there are a much greater number of unmarried servants about every house in the country than are needed, and who are waiting for a house-man's place becoming vacant.

The country abounds in excellent pasture, and is better adapted for the rearing of cattle than the culture of grain; but still considerable difficulties are experienced by the husbandman in this department, and particularly in regard to winter provender. The general breed of horses in Norway are small, but well-proportioned, lively, hardy, and often extremely beautiful. They climb and descend the rocks with surprising address, and display great courage in the combats which they must maintain with the bears and wolves. In order to preserve their strength and spirit for repelling the attacks of these wild animals, they are never cut in some districts; but, in consequence of this practice, they become very unmanageable, and almost as dangerous to one another, in their quarrels, as the bears and wolves of the forests. Unless in the stables of the rich proprietors, they seldom receive any oats as food, and after the pasture of summer is at an end, they are fed chiefly with hay, cut straw, or sometimes even with dried leaves. Frequently they are never shod; and are very commonly ridden without saddle or bridle, and with nothing but a cord fastened to a wooden bit. The horned cattle are generally of a small size; and many of them are sent to pasture at liberty on the islands along the coast, where they thrive well, but become so wild as to require the skill of the hunter to retake them. In the lower districts, they form a part of the farmer's stock in the usual manner; but, in the more elevated tracts, they constitute the principal wealth of the inhabitants. The cows especially become more valuable towards the north, where a very poor animal will cost 20 dollars, while at Drontheim a good one may be procured for 15. In the middle of May, the cows are put out to the meadows, and in June are driven to the mountains, or into the heart of the forests, where they remain till the month of August or September. They are watched by a few of the most active young men, who are provided with well trained dogs for security against the wolves and bears; and a few female servants are accommodated in temporary cottages, where they make cheese and butter from the milk.* Sometimes a little hay is cut and stored in some proper repository, till it can be brought down in sledges during the winter season. The cows on their return are pastured in the meadows, till the snow sets in about the middle of October, when they are removed to the stables, and fed with straw and a little hay; but frequently they are obliged to be contented with buck branches, dried leaves, lichens, sea-weed, reeds, bark of trees, and even fish-heads and fish-bones ground. Nay, in Roras, and a few of the valleys around Drontheim, they are actually supported by eating the dung of the horses, which is collected for the purpose, and sometimes boiled with a little meal into a mess, which fattens cows, sheep, pigs, and poultry, and the horses themselves.

The sheep of Norway are of the same breed with those of Denmark; but in some of the southern districts the English breed has been introduced. Many flocks are left to themselves on the islands, and are only visited when about to be shorn, in the month of May; but some of the other flocks are shorn two, or even three times in the year. Many goats also are kept in the country; and their milk is mixed with that of the sheep in making butter and cheese. Hogs are not very abundant; nor are geese, ducks and other poultry, made an object of much attention among the peasantry.

In most districts of Norway, a principal part of the husbandman's profits are derived from the cutting of timber for fuel, inclosures, making of roads, or the purposes of building, and from the preparations of tar, ashes, and charcoal. Many of the forests are the property of the crown; others belong to individuals; and some are in a manner common. Various laws are enacted for the regulation of the respective rights to make use of the forests; but in general great abuses are committed in this respect, and little economy is practised in the article of wood.

The destruction of the wild animals, with which these extensive forests abound, forms another occupation of the peasantry, both as a measure of preservation from their ravenous inroads, and as a source of profit to the hunters. There are various kinds of bears, brown, black, and white; some of which are very large, and attack the horses and horned cattle; while those of a smaller size devour the heaps of corn in the fields during the autumn. Various means are employed for thinning their numbers—fire-arms, snares, dogs. Their skins are sold from 8 to 18 rixdollars, according to their size and quality; and the flesh of the cubs, particularly, is often used as food by the country people. Wolves also are extremely numerous, and prey upon the horses, as well as upon the large and small cattle. They avoid every thing which hangs over their heads, and therefore shun the woods as much as possible; so that the best protection against their depredations is a hedge inclosure, sufficiently high to prevent them from leaping over, and through which they will not attempt to creep. In the long twilights of the winter season, they become formidable to travellers, especially on the extensive lakes, where they assemble on the ice in great numbers; and are frequently frightened from making an attack by the following simple contrivance, mentioned by Von Buch." "A rope is fastened to the hinder part of the sledge, and so long as it can be preserved, it hangs down loosely, and is dragged along the track of the sledge. The small irregularities of the way raise it every now and then aloft, and make it turn in perpetual serpentine windings. This frightens the wolves: they dare not venture an attack; and, in dread of this dancing monster, they remain at a secure distance." Besides the usual modes of hunting them, they are frequently destroyed by poison spread upon the dead carcass of a sheep or lamb; and rewards are proposed by government to encourage the destruction of wolves and bears. There are in Norway many other wild animals, whose skins reward the toils of the peasant in preserving his fields from their depredations, particularly lynxes†, whose furs bear a high price; foxes, white, red, and black; hares, white in winter, and grey in summer; ermines of a fine white colour, particularly in the northern districts; squirrels, martens, otters, and a few beavers; stags and roe-bucks in some of the southern cantons; but the elk, in consequence of the slaughter made among the females by the hunters, (though often prohibited by public authority,) is becoming a rare animal in the country. There are great numbers of the mouse called lemming, which multiply among the furze and other underwood to an extraordinary degree; and, at certain seasons, migrate in multitudes, always directing their course towards the frontiers of Sweden and the Gulf of Bothnia, advancing in a straight line over every obstacle, and producing a sensible damage in the fields through which they pass; but their ranks are greatly thinned in their progress by their natural enemies the bears, rein-deer, foxes, and martens. The birds are numerous, particularly those which frequent the lakes and the sea-shore; and they are taken and destroyed in great quantities for the sake of their down, which forms a valuable article in commerce. The natives encounter great risks in this pursuit, by clambering among the rocks, suspending themselves from the summits of the most tremendous precipices, in order to catch the birds in their nests.

Several of the small uninhabited islands are considered as valuable property, on account of the eggs of the sea fowl, chiefly the sea-mew, which breed upon them, and which do not easily leave the place which they have once chosen for that purpose. When the proprietor of one of these egg vars comes in quest of the eggs, the birds having become acquainted with his appearance, remain quiet, and only fly to a short distance, as only the superfluous eggs are taken away, and one or two always left in the nest, to which they soon return. But when foreign vessels and strangers happen to arrive and carry off the whole of the eggs, the whole flock, to the number of many thousands, rise in the air with the most piercing cries, and fall down again upon the nests as in despair. Upon a repetition of such spoliation, they completely forsake the place. In several of the northern islands, eagles are very common, and so ferocious, that, besides destroying the lambs and smaller animals, they are said even to attack and sometimes to overcome the oxen. In order to effect its purpose, the bird first plunges in the sea, and when completely wet, rolls itself on the shore till the feathers are covered with sand; then rising into the air, and hovering over the ox, shakes the sand and small stones into the eyes of the animal, and flaps his face with its powerful wings. The blinded oxen run about in terror and rage till they fall down completely exhausted, or dash themselves to death over a precipice, when the eagle devours them at its leisure.[*] All kinds of hunting and fowling are entirely unfettered by game laws; and an attempt made in 1730 to restrict this freedom, produced such increase among the wild animals, that it was found necessary to repeal the new enactments.

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* The cattle are called together by trumpets about six feet in length, made of splinters of wood bound together by withers.

† There are three kinds of lynxes in the country, which are called goube by the common people; the wolf-goube, the fox-goube, and the cat-goube. They are extremely rare, and their skins are sold upon the spot for 25 or 30 dollars. The cat-goube exactly resembles a tiger, and is more destructive among the cattle than any other wild animal in the country. They only suck the blood of cows, of which one of them will destroy twenty in a night; and of sheep and goats they devour only the middle, with a part of the head.

The lakes, rivers, and coasts of Norway are frequented by shoals of fish, particularly cod, ling, whiting, salmon, mackerel, and herring; and a great proportion of the inhabitants along the western coast, find their principal employment in the fisheries. It is thought indeed, that, notwithstanding the various advantages of this occupation in a national point of view, too many individuals are attracted to the pursuit, which, though often highly lucrative, is attended with great risks and losses, and diminishes the number of hands who might be employed in improving the agriculture of the country. Von Buch calculates that fully the half of all the grown men who inhabit the Nordlands, through an extent of 100 geographical miles, are collected at the fishing station of Lofodden every spring, besides 300 vessels from the southern ports, each filled with seven or eight men, so that in this single station there are more than 20,000 individuals engaged in fishing during the months of February and March. He calculates also, that at these islands of Vaage nearly sixteen millions of large cod and tusk are taken every year. The fish are supposed to seek the shelter of the calm straits among the islands for the repose which they require in spawning, and they also pursue one another as prey. The smelt or lodde, supposed to be the *salmo eperlanus*, (so remarkable for their odour, that the fishermen distinguish their approach at the distance of ten English miles,) first make their appearance in pursuit of the sea crab, and are followed by the cod and sey, the former of which drives them into the fiords, while the latter endeavours to surround the shoals and keep them out at sea. These again are pursued by numbers of whales; but on account of the service which they are supposed to render, by driving the fish towards the coast, they are not attacked, and only the small whales which enter the fiords are taken. In the cod fishing, lines and hand-lines are used, especially by the poorer fishermen; but large nets above twenty fathoms in length are generally employed, and are found to be much more successful.

It is still so much the practice in Norway for every family to fabricate a great part of the articles which they require for domestic purposes, that manufactures, and even the ordinary trades, have made little progress in the country; and the distance at which the peasants commonly live from each other, tends to continue this state of things. The following list of persons employed in distinct trades at Christiania in 1793, among a population of 10,000 people, may convey a curious view of the subject.

Bakers	10	Pin-makers	5
Barbers	3	Wig-makers	10
Horners	1	Lace-makers	1
Book-binders	4	Dyers	5
Stone-cutters	1	Curriers	11
Coopers	7	Tanners	3
Distillers of brandy	1	Plasterers	2
Furriers	4	Glaziers	2
Tin-smiths	7	Goldsmiths	6
Armourers	2	Glovers	2
Hatters	7	Rope-makers	1
Wheel-wrights	8	Sail-makers	1
Instrument-makers	2	Saddlers	6
Pewterers	3	Grinders	5
Makers of cards (for wool)	5	Shoemakers	29
Button-makers	2	Carpenters	3
Braziers	2	Weavers	3
Engravers	1	Tailors	22
Comb-makers	1	Lock-smiths and Farriers	14
Carders	2	Joiners	1
Painters	7	Spur-makers	1
Masons	2	Coach-makers	4
Furbishers	1	Watch-makers	8

In 1801, Von Buch represents the same town as containing 110 shop-keepers, 220 retail dealers, and 24 master artizans.

The peasantry not only make the coarse cloth with which they are clothed, but also their furniture, utensils, tools, shoes, boots, saddles, and harness: and in the most retired spots, among rocks and mountains, are found even self-taught clock and watch-makers, and carvers in wood and stone, whose works discover an astonishing degree of native genius and intelligence. There are nevertheless a few public manufactories in some of the towns, soap-works, and houses for refining sugar; cloths, carpets, and flannels made in the correction houses, linen manufactories at Drammen, roperies at Christiania, Fredericshald, and Drontheim, salt and saltpetre works at the last mentioned place, besides a recent establishment for preparing colouring matter from lichens. A great deal of work is done in the preparation of iron; and in most of the establishments for this purpose, kettles, pans, iron plates, and nails, are fabricated. At Mioss there is a large foundery for casting cannon, and a manufacture of works in iron and steel. There are four extensive glass-works for the supply of these establishments at home, as well as for exportation to other countries; great quantities of potash and soda are prepared every year. Earthen ware is made in several places, but the largest manufactory of that article is at Stordalshalsen; and at the same place are works for burning tiles and lime. At Vardal, a village in the Drontheim, gloves are made in a parti cular manner, which are held in high estimation for their superior softness, and highly agreeable smell. The preparation used for this purpose is kept secret, but is supposed to be made of the bark of the elm tree. One of the greatest and most lucrative of the Norwegian manufactures, (if the mere preparation of the raw materials can be so named,) is the cutting and dressing of masts, beams, rafters, planks, and laths, most of which is done by saw-mills on the rivers; but even in this species of work, rough as it may appear under the name of manufacture, there is a nicety required, which the eye of the merchant can distinguish, and which has considerable effect upon the foreign demand. "The scrupulous and precise Englishman rejects the deals of Drontheim, and sends them to his less fastidious neighbours in Ireland, though the price of those of Christiania and Frederickstadt is much higher. This is not so much owing to the superior quality of the tree, as to the uniform thickness of the plank, and the accurate parallel of its two planes, with several other minute circumstances known only to the sawyer and the delicate English merchant." The floating of the timber down the river, and the carriage of the smaller planks by sledges from the mountains, forms a considerable portion of the national industry. The quantity of timber thus collected in the magazines of the ports, particularly at Christiania, resembles wooden towns laid out in streets and avenues. The noise of the country people bringing the timber continues without interruption so long as the snow lasts. They deliver over their boards to the overseers, who mark on their backs with chalk in letters and figures the place to which the boards were brought, and the number of them. It is a singular enough sight to see these boors hurrying away with all possible expedition to the counting-houses of the merchants, in the quartale, with this original species of obligation on their shoulders. By stopping on their way, or engaging in any other business, they might rub out the marks on their coats, and thus extinguish for ever all evidence of their debt. When they appear before the treasurer, they have no occasion to say a single word. They present their shoulders, and are immediately paid.

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[*] Von Buch was satisfied of the truth of this singular instance of sagacity, by the distinct and circumstantial accounts which he received from different persons in Norway.

Another source of occupation in Norway is the digging of the mines, and the various operations connected with the preparations of the metals for home use or foreign trade. This portion of native manufacture appears to have been followed since the fourteenth century; but it was chiefly by the encouragement given by Christian III. (who sent miners and workers at the forge from Germany,) that the mines were brought into a more flourishing state, and better management. The right to all mines is retained by the crown; but this may be renounced in favour of those who discover the mines and undertake the working of them, upon whom various privileges are conferred. The silver mines of Kongsberg employ 2500 workmen, most of whom are the descendants of German miners, and require annually 1200 loads of charcoal, and 30,000 of wood for burning, besides what is wanted for building. The produce of the different mines has varied greatly according to the modes of prosecuting the work. The gold mine of Edswold in the district of Rommerige, discovered in 1758, has not yet defrayed the expense of working it. The silver mines of Kongsberg, from the year 1623 to 1792, produced 25,130 573 rixdollars; but the expenses have been very considerable, and the clear profits very limited. The copper mines of Roras, from 1646 to 1791 produced 337,863 skeppunds of refined copper, worth above 17,000,000 of rixdollars, and yielding in some years a clear profit of 149,162 rixdollars. The iron mine of Laurvig yields annually about 7000 skeppunds of bar iron, and 2000 of cast iron; that of Mioss about 4000. Several others yield about the same amount as the last mentioned; and the total annual produce from the iron mines is estimated at 40,000 or 50,000 skeppunds. The cobalt mines of Fossum yielded, in 1792, 2817 quintals, valued at 38,709 rixdollars. The salt works of Norway have not succeeded so generally, in consequence, as has been supposed, of a deficiency of saltness in the sea-water; but one establishment at Valloe, by using foreign salt to facilitate the operation, has begun to prosper, and produces annually about nine thousand tons, yielding a clear profit of 11,770 rixdollars.

The peasantry display a truly wonderful ingenuity in carving vessels and other articles of household furniture with their knives. They ornament knife-handles with differently coloured wood, beautifully inlaid; cut out bowls and cups as if they had been turned; and manufacture the most elegant utensils of all sizes, from a cabinet to a snuff-box, without any other instrument than their knives.

The internal trade of Norway is very considerable along the coasts, particularly in the gulf of Christiania and the neighbouring bays, which form a kind of natural canals, running into the country. But, throughout the inland tracts, communication is greatly obstructed by the precipitous mountains, impenetrable forests, and bottomless marshes. The principal roads, however, have been greatly improved. One of them from Christiania to Drontheim is carried over the Dovrefieldt heights, through very dreary tracts and difficult passes; but the horses of the country are so remarkably steady and well trained, that few accidents take place. The number of travellers is too limited to support a regular succession of post-horses; but the peasants are obliged, in their turns, to furnish horses at a regulated price, which is in general too low to recompense the loss of time. During winter, sledges are used in travelling, and in summer small Swedish cars; but, in the spring season, during the whole of April, and the first half of May, all communication is interrupted by the wet state of the roads, which are neither frozen enough to support the sledge, nor dry enough to admit of the car. The cars also are broader than the sledges, and cannot go in their tracks, which alone are first clear of snow; and even a single horse is continually in danger of sinking into hollow places covered with the half-melted snow and ice. Nay, for some time, it is very difficult in certain places to conduct a heavy carriage along the roads; and Von Buch gives the following description of the passage over Tellegrod in Vardalen: "The earth freezes in winter for a depth of several yards; and when the thaw comes on in spring, it is long before the warmth can fully expel the frost from the ground. Hence the winter has been long past on the surface, and the earth become dry and firm, while the undermost rind remains still frozen. The middle thawed part remains beneath the dry surface like a morass, and cannot penetrate deeper into the earth. Such places on the road cannot be known, and horses and coach sink at once like a vessel at sea. The firm rind shakes for a great way around, and rises and falls in continual undulations. The carriage dances, the horses take fright, the crust immediately gives way, and the horses and carriage sink for a number of feet into the abyss. The common expression at parting to all strangers who travel in spring is, throughout Norway, "Heaven preserve you from Tellegrod;" and truly they are in the right. It is frightful to see the carriage and horses rolling over the firm ground, as if convulsed by an earthquake, every moment to expect to see the ground open and swallow them up." The rivers which water the country, though they are of great service for floating down the timber, are so interrupted by falls and rapids, that they cannot contribute much to inland navigation, unless means were employed to alter their course. Besides weekly markets at the principal towns, there are annual fairs, which bring the country people together from a great distance with their domestic produce, and some of these are held in the interior of the country for the convenience of the more remote districts. On these occasions the roads are crowded with sledges loaded with tallow, cheese, butter, and hides, for which they generally find a ready sale; and with the price of which they purchase in return, corn, malt for beer, iron, and ironware, fish, and a variety of small articles which administer to the comfort of existence. At the commencement of winter, also, thousands of oxen are driven into the towns, to supply the inhabitants with their necessary winter provisions. In like manner the great staple commodities, deals and iron, are brought down on sledges during winter, or in summer by means of horses and cars, which return with provisions and other necessaries.

The principal trading towns are Christiania, Frederickshald, Christiansand, Drontheim,* and Bergen; but there are about 20 more, which may be counted as maritime stations, and which, more or less, partake in the foreign commerce. Of these towns Bergen has most connection with Holland; Christiania with Great Britain; and Drontheim with Ireland. The Dutch bring with them spices, drugs, garden-seeds, tobacco pipes, and paper; and take in return rape-seed, timber, charcoal, tar, salt, and dried fish. The British bring coals and various manufactures; and take back dried fish and timber; but in regard to both of these countries the balance of trade is considered as in favour of Norway. In 1768, the foreign trade was stated as follows:

	Exports.		Imports.	
	Rixdollars.	S.	Rixdollars.	S.
Government of Christiania,	513,440	9	465,748	82
————— of Christiansand,	103,660	56	957,780	86
————— of Bergen,	695,760	75	421,754	64
————— of Drontheim,	401,507	93	254,999	89
	1,714,369	41	1,238,284	33

In 1799 the shipping of Norway engaged in trade, and consisting of vessels carrying above ten lasts, was distributed as follows:

	Vessels.	Lasts.		Tons Eng.
In the govern. of Christiania,	283	22,627	1 ½	2,516
————— of Christiansand,	348	16,794	1 ½	2,310
————— of Bergen,	53	6,906		1,035
————— of Drontheim,	63	3,142	1 ½	481
	747	49,470	1 ½	6,336

In 1799 there were exported of wood 1169 cargoes, amounting in all to 86.574 lasts, of which more than one half were to England; two thirds of the other half to Scotland and Ireland; and the remainder chiefly to France, Holland, and the German ports. In the same year there were exported of fish 261 cargoes, amounting in all to 8,958 lasts, of which the greater part were to Spain, the Mediterranean, France, and Embden.

The general exports of Norway are hides, iron, train-oil, tallow, butter, dried and salt fish, timber and planks, horses, and horned cattle, silver, alum, Prussian blue, copper, and iron. The principal imports are wine, brandy, salt, grain, linen, hardware, and various luxuries.

The Norwegian traders frequently sail to the Mediterranean with their own produce; procure freightage for Hamburgh, from which they proceed to the Baltic; and there load with corn for their own ports.

The population of Norway must always bear a small proportion to its geographical extent; but is capable of being increased above its present amount; and in consequence of recent political and agricultural arrangements, has begun to make a very rapid progress. The most populous towns are Bergen, containing 18,000; Kongsberg 8000; Christiania 10,000; Drontheim 8840; Fredericksnald 4000; Christiansand 5000; Vosse Vang 4000; Evindvig 4000. The amount of the whole population, according to a public enumeration in the beginning of 1801, was 910,074. of which the cities contain about one eighth part, and which gives the rate of 100 individuals to every square mile over the whole kingdom. In some places, particularly in Hedemarken, there are above 1000 inhabitants to the geographical square mile, which may be considered as the maximum of population in the country; but over the southern provinces in general there are only 500 or 600 to the square mile; and in the northern districts not more than 20 or 30; nay, in some places in higher latitudes, and even in the elevated region of Dovrefieldt, not more than three. The annual proportion of births to the whole population is as 1 to 35; that of deaths as 1 to 49; and that of marriages as 1 to 130. Children are robust and healthy in Norway, and old age becomes exempt from the harder toils; but the fatigues and dangers of the sea, the mines, and the fisheries, occasion the greatest mortality among the youth and the middle aged. Out of 18,354 who died in the year 1799, there were 208 individuals between 90 and 100 years of age. The population has made considerable progress since the beginning of the 19th century; which has been ascribed to the increase of marriages in consequence of the change in the military service, into which the peasants are now taken at an earlier age, so as to be discharged before having passed the prime of life, and in which they are allowed to marry when they please, without depending as formerly upon the permission of the officer and the priest.

The form of government is the same as in Denmark. There are governors appointed over each of the four governments into which the kingdom is distributed, and sub-governors over the provinces, into which these governments are subdivided. No viceroy has been appointed since the reign of Christian VI.; but the governor of Christiania is invested with the general superintendance of the whole kingdom. The laws and administration of justice are also similar to those of Denmark, except a few alterations required by the different circumstances of the country. The judges in the inferior tribunals, assisted by a certain number of citizens or husbandmen, go from place to place in the country districts, and hold the assizes at different terms; but they must hold them once a month in every bailiwick. Formerly there were provincial courts held three times a-year, to which appeals were made from the inferior tribunals, and from these provincial courts appeals were carried to the superior court of Christiania, from which, in certain cases, appeals were remitted to the supreme tribunal at Copenhagen. But since the year 1797, it is appointed that there shall be a superior court in each government, consisting of one judge and four assessors in the government of Christiania, but in the other three, of one judge and two assessors, and that the head governor shall preside in these courts, not as a judge, but for the maintenance of order and the support of their dignity. In many places the parties plead their own cause without the aid of advocates, and justice is administered throughout the country with the greatest regard to personal liberty, as well as with much primitive simplicity of form. Feudal usurpations had never acquired so wide an influence in Norway as in most other European countries; and hence there are few privileged estates or individuals in the kingdom. The two earldoms of Laurvig and Jarlsberg enjoy the prerogatives of the courts of Denmark, and a small number of domains are exempted from taxes by old letters patent of the kings. The clergy, the schools, and several civil offices, have the use of certain lands, allotted by government for their support, and particularly the hospitals and religious institutions possess considerable districts with certain immunities. The greater parts of the lands in Norway are possessed by the peasantry, and are held by a singular tenure, which appears to have been originally designed to encourage the husbandman, but which had begun, in some degree, to partake of the principles of feudal appropriation. These lands were bound by a species of entail to be transmitted from father to son, without any division; but, since the year 1769, they may both be divided and sold, subject to a family-claim of re-purchase called Odelsgaard, or right of inheritance. This law entitles the proprietor of such freehold estates, or the nearest heir of the family, to redeem the property, by paying the price at which it was sold, provided he announce his intention of doing so immediately after the sale, and come forward to make the purchase before the estate has been fifteen years out of his family, or ten years in the possession of the new proprietor. This custom, doubtless, tends to attach the peasantry to their native place, and to stimulate their improvement of possessions so carefully secured to the family. But, on the other hand, it diminishes the value of an estate which has once been sold, and discourages all attempts to improve a possession rendered so precarious.* There are other properties which neither enjoy any immunities, nor are liable to this right of inheritance, and these are chiefly in the hands of the labouring peasantry. Many lands also are let as farms, and the tenants are free from many burdens which oppress the Danish farmers.

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* The proper name of this city is Trönyem, pronounced Trunyem. It was anciently called Nidrosia.

The revenue drawn from Norway arises from nearly the same sources as in Denmark; such as, land-tax, tithes of grain, fish, iron and copper, capitation-tax, customs, stamps on cards and paper, a per-centage upon income. The revenue amounted in 1787 to 1,140,230 rix dollars, but is understood to have received a considerable increase since that period.

A national militia is regularly maintained in the country, the amount of which is in a great measure regulated by the population, but which of late has generally amounted to about 26,000 men, of whom 8000 composed the corps of Landvaern, or the country's guard, whose services are restricted to the defence of passes, and the garrisons of fortresses. The kingdom is divided into a number of small districts, each of which furnishes a militiaman, who serves ten years, and is then transferred to the Landvaern, where he serves six years more before receiving his discharge. Formerly the peasants might be taken at any age into the army under 36, and the officers used to prefer them between 25 and 30; but, by a recent regulation, they are taken first at 20, and then at 22, till the requisite number be completed. The militia, in time of peace, are only exercised twelve days in the year. There is one corps which merits a particular description, who are trained to the use of skates, and whose duty it is to climb the mountains in case of invasion, and to harass the enemy among the defiles. They are clothed in a short jacket, pantaloons, leather bonnet, and great coat; and armed with a carbine, long hunting-knife, and staff, pointed with iron. Their baggage is conveyed on sledges dragged by men. There are also some volunteer corps, composed of the miners near the frontiers.

The principal fortifications in Norway are those around Fredericshald, particularly the fortress of Fredericstein, situated on a high rock above the town, at the siege of which Charles XII. of Sweden received the death-wound which terminated his frantic career. Fredericstad, near the last mentioned town, Aggerhuus, near Christiania, Frederieswarn, in the county of Laurvig, and the citadel of Vardochus, in Finmark, the most northerly fortification of Europe, are also places of considerable strength.

The religion of Norway, and its ecclesiastical polity, resemble that of Denmark. The king nominates to the greater part of the benefices, and there are about 518 clergy of all ranks in the country. There are a few individuals connected with the reformed churches, but not a sufficient number to form regular communities. No Jews have ever found a footing in Norway; and the apprehension of their engrossing the traffic in metals is supposed to have contributed chiefly to their exclusion. There are several missionaries sent to Lapland by the bishop of Drontheim, who suffer severe privations among the miserable inhabitants, and who receive a salary of 100 crowns per annum. The means of education are very limited in Norway. Some districts have no stationary schools, and are only visited occasionally by teachers, who go from house to house: but means have beem employed by several patriotic societies for remedying this defect. Several villages have grammar schools, like those of Denmark. The youth who wish to prosecute a course of literature and science, are under the necessity of repairing to the University of Copenhagen; but, for some time past, a plan has been in agitation for establishing an University at Christiania; and there are, in the mean time, at Bergen, Drontheim, and other principal cities, academies instituted for imparting to young persons the elements of general knowledge. The Gymnasium, a public school of Christiania, supplies, in the mean time, the place of a university; and, besides the rooms required for the instruction of the youths, contains several collections, and a very useful library, which is open to the citizens. There is a military academy fronting the school-house, where 100 cadets receive their education, and which is supported almost wholly by the contributions of wealthy individuals.

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* According to the law of succession, all the brothers divide the property equally on the death of the father, and the daughters receive the half of a son's portion; but frequently the land is valued, and the elder brother retains it, upon paying to the rest of the family the price of their shares.

The Danish language is also the vernacular tongue of the Norwegians, who are distinguished by a rapid and forcible utterance of their words, and in this respect resemble the Swedes more than the Danes. In some of the northern districts there are still perceptible many expressions of the ancient Gothic, which once formed the language of all Scandinavia, but in the principal towns the dialect is purer than in Denmark itself, or even in Copenhagen.

The progress of literature in Norway, as in Denmark, was very slow till about the middle of the 18th century. Torfæus, a native of Norway, was one of the first and most distinguished native writers, and is particularly celebrated for his Historia Norwegiana, in which he has displayed considerable research into the ancient history of the north. Schoening and Stroem have done much honour to their native country, the one in the civil history, and the other in the natural history of Norway. Vessel and Tulin, who rank with Evald among the fathers of the Danish poetry, were natives of Norway. One of the latter of the Norwegian writers was M. Falsien, Counsellor of State, and President of the High Court of Justice in Christiania, who died in 1808, and who was much distinguished by his pleasing poetical pieces, as well as by a few dramatic productions, especially his comic opera of Dragedukken. The drama is, indeed, the favourite subject of the Norwegian men of letters, and a theatre exists in almost every town, in which the principal persons of the place perform the part of actors for the amusement of themselves and of their fellow-citizens. They discover also a great taste for music in occasional concerts and operas.

Several learned men in Norway formed a society of the sciences at Drontheim, and their transactions, written in the Danish language, contain chiefly disquisitions on natural history, physics, and agriculture. Since the year 1792, a topographical society has been instituted in Christiania, composed of Norwegians who take an interest in opening up the knowledge of their country, and who publish a periodical work, entitled, the Topographical Journal of Norway, which has a considerable circulation, and is held in high repute among the subjects of the Danish crown. There is a collection of paintings and prints at Christiania, which belonged to Chamberlain Ancker. Several of the clergy are distinguished by their scientific attainments; and one of the most distinguished men of the present day, Provost Pihl, of Vang, is said by Von Buch to possess such a collection of astronomical instruments, as is to be found in few observatories; by means of which he has determined with accuracy the situation of the eastern coast. This individual has collected a number of meteorological observations, which will furnish ample data for ascertaining the climate of the north, and is celebrated for his skill in mechanics, which he applies to the useful purposes of life, as well as the construction of his philosophical instruments.

In every parish there are two or three schoolmasters, according to its size, selected by the clergyman from the most learned of the peasants, and confirmed by the bishop; it is affirmed, that all the common people are able to read, and most of them to write. The farmers read the gazettes, and converse freely on political subjects.

The national dances of Norway are different from those of Sweden. The most common are the two following: one called Halling, which resembles tumbling more than dancing, and in which the performer, standing upon his head, kicks his heels about in the air; and another, called Polsk, resembling a waltz, in which the male dancers exhibit a number of lascivious attitudes.

When a marriage takes place in Norway, open house is kept to all comers for a whole week. Every neighbour and relation of the bride and bridegroom brings provisions as a contribution to the feast, and the new married couple are expected to provide beer and brandy. When the guests take their leave, they make presents to the married pair, according to their circumstances and their consanguinity, so that generally 100, and sometimes even 300 dollars are collected for the young couple.

In the towns, a stranger is expected to leave his card with the general commandant, and with the principal people; and if he bring letters of recommendation, the persons to whom they are addressed conduct him round to call upon other families. After this ceremony, invitations pour in upon him from all quarters, in a much greater number than it is possible for him to accept, and the houses are thrown open to strangers in the most generous and hospitable manner.

The natives, even of the better class, generally rise with the sun, when they take a slight breakfast. At nine they have a kind of luncheon, which they call *duel*. At twelve or one they dine. The dinner is followed by coffee; and, in the evening, they drink tea, play at cards, and conclude with punch. They usually sup about ten, and do not go to bed very early. In summer the lower orders of people sit up all night, and take no sleep for a considerable time; but very often make Sunday their sleeping day, and during the winter season make up abundantly for their short repose in summer.

In all the parishes voluntary contributions are made for the maintenance of the poor, every person intimating what sum he is willing to give yearly; and these funds are managed by persons expressly nominated for the purpose. But beggars are very frequently met with in the towns, and are much more numerous than in Sweden.

The carriages used in Norway are very old fashioned. They resemble a sedan chair placed on two wheels, and made open in front.

The inhabitants of Norway are altogether an uninteresting race, but are found in such various degrees of refinement and civilization as to present the appearance of an assemblage of different nations, rather than of one people. They are usually tall and robust, though rather slender; their countenances flat, and complexion fair, though less so than the Danes; their eyes full of spirit, and their whole physiognomy expressive of energy. Those of the mountainous districts are remarkably healthy and vigorous in their general appearance, capable of enduring the greatest fatigues, and encountering the severest inclemencies of the weather. Those who reside on the coasts are of a smaller size, but are the most hardy and adventurous mariners in the world;

and, even in the month of January, when they can reckon upon the light of the moon, companies of men and women pass whole days and nights upon the sea in open boats, in the occupation of fishing. In Lofodden there has been observed a peculiarity of features among the fishermen, prominent bones and noses, black dazzling eyes, sharp and determinate features, and sometimes true Turkish physiognomies, so as to countenance the conjecture that the Phœnicians had visited and partly colonized these coasts. The women of Norway are much handsomer than those of Sweden; but the men are less athletic than the northern Swedes.

The manners and dress of the people upon the coasts, and in most of the commercial cities, are greatly altered by the introduction of foreign usages, and it is only in the more remote districts that the national character is still retained. This primitive stamp of mind and style of life is beheld in a great variety of stages, according to the vicinity of the people to the towns, and their opportunities of intercourse with one another. "The Swedes, Danes, and Norwegians, assuredly do not differ more from one another than the inhabitants of various valleys, who assemble from all parts to the annual fair. This is one of the most interesting spectacles for every stranger who visits Norway, and for every person who wishes to examine human nature, and to trace by what routes and associations man gradually advances in the progress of cultivation.

"The strong and robust inhabitant of Guldbrandsdalen, in his long coat of the 17th century, and with his little red cap on his head, walks by the side of the comparatively elegant boor of Walders, who, in features and dress, is as unlike him as if he came from beyond the sea. The rich proprietors from Hedemarken pass along as if they were of the inferior order of town's people; and their coats of home-made cloth are cut in an antiquated fashion, as is usual in country places. From Oesterdalen, on the Swedish boundaries, appears a higher class of men; but we may easily see, from their carriage, that it is borrowed from their neighbours. On the other hand, we see the rough and almost stupid native of Hallingdalen in a true national uniform; and the sturdy men of Oevre-Tellemarken still more rough and stupid. They alone yet continue to wear the broad northern girdle round the waist, which the native of Tellemarken embroiders and ornaments in quite a different manner from the other; and in this girdle they fix a large knife, like the Italians, which was formerly as often used by them for attack and warfare as for conveniency. They wear a short jacket, with a sort of epaulette on it; and a small cap on the head; thin short leathern breeches contain in the side pockets all the wants of the moment, and almost always the important small iron tobacco-pipe. Every step and movement of these men is characteristic and definite. They have only one object in view, and nothing which surrounds them can deaden the eagerness with which they pursue that object. The boor of Foulloug and Moss is far from having this distinct character. Nearer to the town his business is also more various, and he looks around him with attention and caution, to discover any little advantages which may bring him easier and more securely to his end; and he no longer lives insulated in his valley, relying on his own individual physical strength; but has become, through common interest and connexions, a part of a nation."

The ancient dress, as observable in some of the more remote valleys, resembles the regimental uniform in the days of Eugene and Marlborough; and the cloth of which the men's coats are made is principally of a stone colour, with red button-holes and white metal buttons. The women of the lower order wear a jacket, with a shining black apron over their petticoat, and a turban handkerchief above the head, beneath which appears a clean laced mob tied under the chin; but while employed in their household affairs, they frequently wear nothing more than a petticoat and a shift, with a collar reaching to the throat, and a black sash tied round the waist. They pique themselves upon having fine linens; and being usually well made, their shapes appear to advantage in this dress. In the maritime districts of Nordland, where the inhabitants are much employed as fishers, they are dressed so much alike that they appear as if in uniform. The men wear earth-brown frocks, close on every side, except at the breast, in the opening of which small blue trimmings run down on both sides; large white trowsers above their boots; a red woollen cap on their heads, with a felt hat above it. In the south of Norway, a scarlet bonnet and white jacket is the usual dress of the peasants; and the gentlemen are clothed in every respect as in England.

There are few splendid buildings in Norway, even in the principal towns; and the greater part of the houses are constructed chiefly of wood, with foundations of stone, plastered, and whitewashed on the outside. The interior is lined with planks, which are covered with oil paint; and the open spaces are filled with pitch, tow, or moss, to exclude the cold. But it is generally observed that the Norwegians do not bestow sufficient attention upon the closeness of their houses, and seem to trust for warmth rather to their immense fires of wood. The roofs are frequently covered with tiles, but more commonly with planks, upon which are laid the bark of the birch tree, with a coat of turf above all, which in summer bears grass and flowers, on which the goats are fond of browzing. The cleanliness of the cottages is very remarkable; and much of their furniture, (such as polished pewter dishes and earthen plates, in rows along the walls, burnished kettles and saucepans, bright wooden bedsteads, chairs and tables, bleached with frequent scowering,) bears a close resemblance to the state of the English cottages in former times. The ceilings, windows, and walls, are frequently painted with showy colours; the tables coloured in imitation of oil-cloth patterns; and sometimes the sides of the walls hung with painted cloth. There are many elegant country seats, which are oblong buildings, consisting of one floor, the outsides painted red, and the frames of the windows green. The walls and beams of the houses are often covered with inscriptions of a moral and religious nature, or expressive of the feelings of hospitality. The dwelling-houses in the country, which are generally situated in the most pleasing and even picturesque spots that can be found, are usually spacious, and commodiously arranged; consisting of three or four rooms on one floor, with large windows, but sometimes with nothing but a square hole in the roof, which serves also for a passage to the smoke, and which is occasionally filled by a wooden pane covered with bladder. In the towns, however, particularly in Drontheim, which is almost entirely composed of wooden houses, these structures have a very neat appearance, and are ornamented with a considerable degree of taste. In this place, the town-house is built in a very noble and simple style; and the ruined cathedral of St. Olaf, which in former times was the great resort of Norwegian Pilgrims, is still the largest and most remarkable edifice in Norway. In Christiania, the houses are almost wholly built of stone; and log houses are absolutely prohibited by the government, on account of the destructive conflagrations which occur where they prevail, and by which almost every town in Norway has at one time or other been reduced to ashes.

The diet of the inhabitants of the towns resembles nearly that of other countries in the north of Europe; but in the country districts peculiar modes of living prevail. At an entertainment given by the better class, the guests place themselves at table without etiquette, and every one sits as he chooses. They continue long at their meals, but converse with much liveliness. They do not remain at table after dinner; and the constant presence of the ladies, who often take the lead in conversation, renders their social meetings cheerful and agreeable. Their dinners are of a very substantial nature, yet not without elegance; and even at supper three or four courses of soup, fowls, ham, fish, &c. follow one another, while perhaps a quarter of veal appears at last as the concluding delicacy. After dinner the company all bow to the hostess, drink her health, and then suddenly rising, push back their chairs with a tremendous noise to the sides of the room. Then they stand for a short time as if they were saying a grace; after which, bowing to the master of the house, and to each other, they shake hands with the host, kiss the hand of the hostess, and conduct the ladies out of the room. Coffee is then served, while some gentlemen retire to smoke tobacco in another room. Tea is then brought in, after which the card tables are set out, and punch served up. A solid supper finally appears, as before mentioned.

Their bread is sometimes made of rye, but generally of oats, and is baked so hard, that when laid in a dry place it may be kept for several years without much alteration. A kind of gruel, or pottage, of barley or oat meal, mixed sometimes with dried fish, or with sour milk, forms, besides bread, the ordinary food of the peasantry, with the occasional addition of milk, butter, cheese, fish, salted meat, and game. A kind of cheese, called gammel orse, or norske, made of butter-milk mixed with yeast, and resembling the best old Cheshire cheese, is a favourite article of food, but which they are not willing to sell: it is usually kept ten years before being brought to table. In seasons of scarcity the *lichen rangiferus* or rein-deer moss, freed from its bitterness by careful preparations, is ground, and mixed with the ordinary flour of which bread is made. This plant, which in the winter season is tender and succulent, like heart of lettuce, has a cooling and juicy taste in the mouth, but warms the stomach after it has been swallowed, and might form a very useful article of food, were not the natives strongly prejudiced against the idea of being fed with the fodder of their cattle. Even the bark of the fir tree is sometimes employed in the same way in cases of great necessity. The innermost rind of the most vigorous young trees is taken for this purpose, hung up in the air for several days to dry, baked in an oven, beaten on wooden blocks, then pounded as finely as possible in wooden vessels; and, finally, ground in the mill into coarse meal, like barley or oats. It is then mixed up with thrashed-out ears, or a few moss seeds, and made into thick cakes. This bitter and astringent food, which the peasants, who are reduced to the use of it, are obliged to wash down with water, renders the body weak and relaxed, and occasions an oppressive burning about the chest. The peasants of Norway are, nevertheless, generally well clothed and lodged, and provided with more comforts of life than the common people of most other countries. In the summer season they sleep in a state of nakedness, in order to save their linens, and in this respect resemble the peasantry of Italy.

The character of the Norwegians as a people is more interesting and estimable than that of most other nations. Their expressions are clear and energetic, their answers distinct and correct, their questions pertinent and judicious, their reflections often profound and intelligent, beyond what could be imagined in their limited opportunities of education. There is a generosity of heart and elevation of mind about them, which gives to their manners a very frank and decided stamp. They speak and act in the full spirit of free men, open and undaunted, yet never insolent in the presence of their superiors. They salute one another by opening their hands; and, even to persons considerably above them in station, they express their thanks, not by words or bows, but by a cordial shake of the hand. They were generally treated with kindness, humanity, and patience, by the functionaries of the Danish government, which they repaid with the most hearty confidence. Many of the peasants pride themselves upon their descent from the ancient nobles, and are careful to procure for their children matrimonial connections only among their equals in birth and blood. They are reproached with being slow in reconciliations; but are obliging, hospitable, and liberal even to display, when they possess the means. In some of the cities, there is a cultivated style of conversation, and polish of manners, mixed with the high and independent spirit of the nation, which form altogether an accomplished character, not to be expected in the remote latitudes and limited advantages of Scandinavia; and in some of the inland districts, where the corrupting influence of commerce has not reached, there prevails a pure and primitive spirit of religion, united with a quiet industry, and domestic retirement, which are peculiarly suited to cheer the state of poverty and privation in which their days are spent. They are generally animated by an ardent spirit of patriotism, particularly in the city of Drontheim, which has less dependance upon foreign connections, and may be considered as a kind of insulated territory, in which the true Norwegian character appears in all its native warmth and simplicity. They are of all nations the most sincerely attached to the people of Great Britain. "The welfare of Great Britain," says Dr. Clarke, "was a toast which resounded in every company, and was never given, but with reiterated cheers, and the most heartfelt transports. Every Englishman was considered by the Norwegians as a brother; they partook even in our prejudices, and participated in all our triumphs. Whenever the gazettes contained intelligence of a victory gained by the English, the glad tidings were hailed and echoed from one end of the country to the other; but especially in Drontheim. They sung "*Rule Britannia*" in every company. Their houses were furnished with English engravings; English newspapers were lying on their tables. The Norwegians would have fought for England as for their native land; and there was nothing which an Englishman, as a sincere lover of his country, might more earnestly have wished for, than to see Norway allied to Britain."

The ancient inhabitants of Norway are supposed to have been a colony of the Basterna, a numerous and powerful Gothic tribe; but according to Pliny, Strabo, and Tacitus, they were rather of German extraction. Norway was originally divided into a number of petty principalities, which were first united into one monarchy by Harold Harfager, A. D. 875. The numerous descendants of these princes soon dismembered the kingdom by their conflicting claims; but in the year 1028, the whole country was subjected to Denmark, by Canute the Great. The authority of the Danish princes, however, was frequently disputed; and it was not till the year 1380, when Hager, king of Norway, married the princess Margaret of Denmark, that the two crowns were united. The two countries, however, continued so far separate as to have distinct constitutions and codes of law; and were not formally conjoined as one kingdom till the year 1537. In consequence of arrangements between the courts of Russia and Sweden, to which the British government afterwards acceded, Norway was united to Sweden, in October, 1814, with equal rights and privileges to both nations. See *Tableau des Etats Danois*, *par* Catteau; Von Buch's *Travels in Norway*; Clarke's *Travels in Norway*, *Sweden*, *&c.* (*q*)

NORWICH, a large, ancient, and venerable city, distinguished at an early period by the number and importance of its religious establishments, and of great note in more modern days, on account of its manufactures, is situated not very far from the centre of the more easterly division of Norfolk, of which county it is the capital. It occupies a fine situation, chiefly on an easy eminence, a little above the confluence of the Wensum with the Yare, which, from the sea-port town, Yarmouth, where is its efflux into the German Ocean, is navigable to within less than two miles of Norwich, for boats and barges, which the Wensum floats up to the city.* Thus, the entire distance being only about 25 miles, is facility given to the exportation of the valuable manufactures of Norwich. The city, very extensive, and yet, in great part, surrounded by a wall, most of the gates in which, if not all of them, are, however, now pulled down, approaches nearly to the form of a circle, drawn out, curvilinearly, a little towards the south-east. The streets are very numerous, but unfortunately, like those of most of our ancient cities, also in general very narrow. The market-place, however, situated in the southern and larger of the two portions into which the Wensum divides Norwich, forms a spacious quadrangular area; and exhibits in the diversified character of the buildings by which it is surrounded, together with, especially on a market-day, the motley groups of buyers and sellers spread over its extent, an interesting object of contemplation.

In 1578, Queen Elizabeth made, in one of her progresses, some stay here; but after this time we find, in the political history of the city, little that needs to be stated; especially as we have yet to advert to the *manufactures* of the place. The æra of the introduction of these, Blomefield, the historian of Norfolk, would make the reign of Henry I.; when, he thinks, the fabrication of worsted stuffs was begun by some of the Flemings, whom an inundation had driven from their own country, and begun at the town of Worstead, in this county. Hence the manufacture of this species of fabric was removed to Norwich; and, by a fresh importation of Flemings, drawn over to England in 1336, by the marriage of her king with Philippa of Hainault, was raised to a high degree of prosperity. In 1448, an act passed, appointing eight wardens, four for the county, and four for the city, to watch over the important manufacture, and prevent flimsy goods from going into the market. Such care placed the manufacturers beyond the danger of foreign rivalry; and by the time of Henry VIII., we are told, that, including £60,000 worth of hose, stuffs, chiefly called worsteds, sares, and stammins, were made and sold from Norwich only, to the value, annually, of £260,000. The manufactures as they now stood, however, speedily experienced a decay. But while, in the two intervening reigns, the fabrication of other kinds of goods had been commenced with the reign of Elizabeth, a revival of Norwich manufactures was destined to take place. Harassed beyond measure by the persecuting fury of the Duke of Alva, the industrious inhabitants of the Low Countries were fleeing in hundreds from their native soil, when, with a wise and happy policy, the queen invited those who chose to accept the offer, to an asylum in her own dominions. Numbers did accept the offer. Three hundred are said to have settled at Norwich, and to have soon increased to 1000. By them the manufactures of bays, sares, arras, and mochades, caungeantries, tufted mochades, currelles, and other fabrics, into the composition of which, silk, saitric, and linen yarn entered, was vigorously commenced, and successfully prosecuted. In 1575, they began to make bombazines, for the manufacture of which Norwich has ever since been famous—and a new sort of which, more silky in exterior appearance, is, under the scarcely appropriate, although not new appellation of Norwich crape, just now (1822) in vogue. About the same time, the art of printing was introduced into Norwich, by Anthony Solmpne, one of the strangers. In Defoe's Tour through Britain, the number of work people employed in the woollen, worsted, and silk manufactures of Norwich, is, on the authority of a master manufacturer, his informant, stated to be 120,000: the far greater number of whom must, however, have resided out of the city. In 1721, the court mourning was ordered to consist of Norwich crapes, a circumstance apparently proving that little foreign demand then existed for the article so called. Since then, however, the export trade has been considerable. About 1763, there were employed 12,000 looms, each on an average, annually, producing manufactures to the value of £100; all of them, consequently, to that of £1,200,000; from which sum one-tenth being deducted as the value of the raw material, gave £1,080 000 as the augmented value produced by the process of manufacture. Then, as six persons were on an average kept in work by each loom, the number of individuals employed through the activity of the 12,000 looms, was 70,000. And although since that time the trade has experienced considerable depression, yet was it, from about the year 1790 to the year 1800, computed, that £700 000 worth of goods were not unfrequently manufactured here in 12 months. The chief articles now made are bombazines, worsted damasks, crapes, flowered satins, fine camblets, shawls, cottons, fancy stuffs for both personal wear and furniture, cotton, thread lace, linen, called Suffolk hempen, &c. In being produced at market, the staple manufactured article passes, from first to last, through the hands of about 50 individuals; the earnings of whom vary from 3*s*. to 30*s*. per week. Many women, and even many children, are employed; nor were the manufactures of Norwich ever, we believe, more flourishing than, after all their fluctuations, they are at present. The wools used are chiefly those of Lincolnshire and Leicestershire. Machinery has been extensively adopted. The population of Norwich, which, in 1693, was 28,881; in 1752, 36,169; in 1786, 40,051; and in 1801, 36,854; is now (1822) about 46,000. See Blomefield's *Essay towards a Topographical History of the County of Norfolk;* the *Norfolk Tour;* Booth's *History of Norwich;* the *Beauties of England and Wales*, vol. xi. &c. &c. (v. v.)

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* Some accounts erroneously represent Norwich as situated on the Yare.

NORWICH, a city and seat of justice, New-London county, Connecticut, on the Thames, at the head of navigation, 13 miles above New London, and 38 south-east from Hartford. Latitude 41° 34′ north, longitude, west from London, 72° 05′, and 4° 55′ east from Washington.

The Thames is formed by two streams, the Shetucket and Yantic, which unite at Chelsea landing, and form a fine and commodious harbour. About a mile above its mouth, the Yantic is precipitated over a cataract which enriches the vicinity with some beautiful landscapes, and affords an excellent site for manufacturing establishments. The city contains, beside the common county buildings, and several places of public worship, a woollen factory, cotton factory, two manufactories of morocco leather, two paper mills, five or six tanneries, a carding machine, six grain mills, and six saw mills.

Norwich is composed of Chelsea landing, the town, and Beacon hill. Chelsea landing, at the junction of Shetucket and Yantic rivers, is the port, and seat of commercial transactions. The town is two miles farther to the north-west, and contains the public buildings. Beacon hill is still farther west than the town. Population of the whole township, in 1810, 3528; and in 1820, the city contained 2983; and the residue of the township, 651, forming an aggregate at the latter period, of 3,634.

DARBY.

NOTATION, (in mathematics) the art of adapting arbitrary symbols to the representation of quantities, and the operations to be performed on them. The numerous symbols, which form the language of analysis in the present advanced stage of that science, have been produced by the gradually increasing wants of those who have cultivated it; new and more extensive views continually opening, have compelled them to contract modes of notation already in existence, and the improvements thus introduced into notation, have in their turn directed the attention of the mathematician to wider and more general views of the science.

The advances towards perfection which have been made in the language of analysis, and the generalization which has been introduced into its principles, alternately acting on each other, as cause and effect, have, by their combined influence, produced a language of unrivalled power, enabling the mind to carry on processes of deductive reasoning of almost unlimited length, with scarcely the fear of an error, and with a conviction, that, should accident have introduced one, a careful revision will not fail to eradicate it.

Brevity appears to have been the directing principle which guided the early cultivators of the algebraic art; unaware of the immense importance which, in a subsequent state of the science, would be attached to the language whose foundations they were thus unconsciously laying, they contented themselves with avoiding the tedious repetitions of the same words, by employing one or two of the initial, or, in some cases, of the final letters, to denote them. Such was the case with Diophantus, the earliest author on algebra, whose writings have descended to us. The unknown quantity he denominates *αριθμος*, and to avoid repeating it, uses the final letter ς. He also uses the sign ⋔ or the inverted ψ to denote minus, obviously from the circumstance of its being a prominent letter in the Greek word λειψις. This author has no sign to denote plus, but uses the word at length. He has represented the various powers thus, $\bar{\delta}^{\upsilon}$, $\bar{\kappa}^{\upsilon}$, $\overline{\delta\delta}^{\upsilon}$, &c., meaning the square, cube, fourth power, &c., these letters are the same as those which commence the words square, cube, &c.

The earliest algebraical writer, after the invention of printing, was Lucas Paciolus, or de Burgo; he uses *p̃* to signify plus, and *m* for minus, and indicates the various powers by their two first letters. Such was very nearly the notation employed by his successors, Cardan, Tartaglea, and Ferrari. Stifelius, a German, who published a work, entitled Arithmetica Integra, Norimburg, 1544, added considerably to the use of signs; according to Dr. Hutton, he is the first writer who employed the signs + and —, and also √, to designate the root of a quantity. He had no sign to represent equality, a deficiency afterwards supplied by Robert Recorde; we also owe to him the vinculum $\overline{a + b}$ to connect compound quantities, the other mode by means of parentheses $(a + b)$ being afterwards proposed by Girarde. When Stifelius treated of several variables, he denoted them by the letters A, B, C, &c.

Bombelli appears to have made a most valuable innovation in the method of denoting powers, rejecting the plans of attaching their initials to the radix, he marks them thus, $\underset{\smile}{1}$, $\underset{\smile}{2}$, $\underset{\smile}{3}$, $\underset{\smile}{4}$, &c., an improvement, perhaps more valuable than any which has yet been noticed; nearly a similar plan was adopted by Simon Stevin, who denoted the powers of the unknown quantity thus, $\textcircled{0}$, $\textcircled{1}$, $\textcircled{2}$, $\textcircled{3}$, and he observed that the power whose index is zero, is equal to unity. He, however, went a step beyond his predecessors, and denoted roots by fractional indices; thus, $\textcircled{\tfrac{1}{2}}$ $\textcircled{\tfrac{1}{3}}$ with him represent the square and cube roots.

Vieta flourished several years later than Stevin; he added greatly to the science he cultivated, although he did not avail himself of all the improvements in notation, which existed previously. The most important alteration which he introduced, was that of denoting *known* as well as *unknown* quantities by letters; for the former he employed the consonants, and for the latter the vowels. He appears also to have made the important remark, that negative exponents perform the same office as positive ones, although his view seems rather to have been restricted to whole numbers.

It is a curious circumstance, that the symbol which now represents equality, was first used to denote subtraction, in which sense it was employed by Albert Girarde, and that a word, signifying equality, was always used instead of a sign, until the time of Harriot, who at the same time proposed the signs $>$ and $<$ to denote "greater than" and "less than."

Oughtred, in his "Clavis," appears first to have employed the × for multiplication, he sometimes also joins the letters without any intervening sign for the same purpose.

Such was the origin of the more common signs, which we now employ. An example of the different modes of expressing the same equation will exhibit this more clearly.

Paciolus	1 *cu. m.* 6*ce.* p. 11*co.* equale $6n^{i}$.
Stifelius	1 ℭ — 6 ʒ + 11 2 equantur 6
Bombelli	$1\overset{3}{\smile}.m.\ 6\overset{2}{\smile}.p.\ 11\overset{1}{\smile}$ eguale 6
Stevinus	1 ③ — 6 ② + 11 ①: egale 6
Vieta	1 C — 6Q + 11 N egal 6
Harriot	$1.aaa - 6.aa + 11.a = 6$
Modern	$x^3 - 6x^2 + 11x = 6$

Since the time of Harriot, few alterations have been made in the mode of denoting the more simple operations of analysis, although the science itself has received great improvements. The first step which necessitated the invention of new methods of denoting operations, was the fluxional or differential calculus. Newton and Leibnitz each gave a notation to this new branch of analysis, and their respective followers, entering with more zeal than judgment into the unfortunate controversy respecting the claim of priority of invention, pertinaciously adhered to the notation of their masters, without inquiring into their relative merits, and probably without the knowledge requisite to form a correct judgment on the question, had they turned their attention to the inquiry. In fact, the state of the science at the period at which these modes of calculation were given to the world, could not admit of the formation of a correct estimate of their relative value, and the few reasons which could then be adduced were, on the whole, more favourable to the fluxional notation. It requires, even at the present time, an extensive acquaintance with the subsequent discoveries of the successors of Newton and Leibnitz, and an enlarged view of the present state of mathematical science, duly to appreciate the reasons which concur in rendering the notation of Leibnitz decidedly the best of any which has hitherto been proposed for accomplishing the same object.

As the proper adaptation of notation to the object of inquiry has contributed greatly to the progress of analysis, we propose offering a few general rules for the consideration of those who may have occasion to express new relations, or who may desire to abbreviate those already in use; and we shall compare several of the notations already received with these principles.

The great object of all notation is to convey to the mind, as speedily as possible, a complete idea of operations which are to be, or have been, executed; and since every thing is to be exhibited to the eye, the more compact and condensed the symbols are, the more readily will they be caught, as it were, at a glance.

The first and most obvious rule is, that *all notation should be as simple as the nature of the operations to be indicated will admit.* The reason of this is sufficiently evident, and it scarcely admits of an exception. It must, however, be remarked, that it is, in many cases, absolutely impossible to express the complicated operations required in the highest departments of analysis by formulæ that can be called simple. Still, however, they may be simple with reference to the multiplied relations they express.

The next rule we shall propose is, *that we must adhere to one notation for one thing.* It is particularly unphilosophical, and completely contrary to the whole spirit of symbolic reasoning, to employ the same signs for the representation of different operations, yet instances of the infringement of this rule are occasionally met with; and as several examples are to be found in the works of an author of the very highest reputation, it is more particularly necessary to mark this deviation from the propriety of analytical language.

The notation employed by Lagrange to explain the differential calculus will be considered on another occasion. It is curious to observe, that his zeal for introducing the system of accentuation compelled him to abandon a most valuable contrivance, which he had formerly employed for designating the variations of quantities which harmonized with the notation of Leibnitz, whilst that which he substituted for it, (the system of dots,) besides the inconveniences which it possessed in its original signification, had the additional disadvantage of having been employed in a different sense by all the followers of Newton. In the first edition of the *Théorie des Fonctions*, this notation was not employed, but in the *Leçons sur le Calcul des Fonctions*, published in 1806, the fluxional notation is used for explaining the calculus of variations. The same author has also assumed the quadrant as the unity of angular measure, and represented sin. $\frac{\pi}{2}$: thus : sin. 1, which, unless previously defined, would indicate the sine of an arc equal to the radius.

Another instance of a breach of this rule is to be observed in the *Théorie des Nombres* of Legendre, who, throughout that highly valuable work, employs the sign $=$ in two different senses; first, in its ordinary acceptation; and, secondly, he places it between two quantities, to denote, that when they are divided by the same quantity, they will leave the same remainder. This relation of quantity is of frequent occurrence in the theory of numbers; and the necessity of denoting it with brevity, induced the author of the *Disquisitiones Arithmeticæ* to invent the symbol $\equiv$, and to adjoin (inclosed in brackets) the quantity which is used as the divisor. A different method has been adopted by Mr. Barlow, who, in his *Treatise on the Theory of Numbers*, uses the double *f* (*ff*) placed in a horizontal position. These three methods of denoting the same relation stand thus:

L. $a^n = -1$ G. $a^n \equiv -1$ (mod. p) B. a^n ∾ $pv-1$.

The first of these sins unpardonably against the rule we are endeavouring to enforce; it is much more inconvenient than the use of dots by Lagrange, because, in the instance we are considering, the same symbol $=$ is used in the *same page*, and even in the *same line*, in *two different senses*. It has also the disadvantage of requiring the divisor to be expressed in words.

This innovation in the use of a well known sign probably arose from too strict an adherence to an admitted rule: *Not to multiply the number of mathematical signs without necessity.* We may, however, here be permitted to observe, that the necessity existed; and it is acknowledged by Gauss, whose notation, although much preferable to the one we have been criticising, is decidedly inferior to that of Mr. Barlow. The preference we have given to this latter is also supported by another rule too evident to require much argument. *When it is required to express new relations that are analogous to others for which signs are already contrived, we should employ a notation as nearly allied to those signs as we conveniently can.*

That analogy ought to be our guide in the formation of all new notations, is a truth, which, like many others, has been felt and acted upon, although it may not have been stated in express terms: and it was probably this feeling which induced Stifelius to inquire into the meaning of negative exponents, the consequence of which was the establishment of the connection between the direct and reciprocal powers, a deduction which, when enlarged by the consideration of fractional exponents, was no mean addition to the state of algebra at the time it was suggested.

It has long been usual to denote known quantities by the first letters of the alphabet, and to represent unknown ones by the last letters. In the sixteenth and seventeenth centuries, the practice used to be to employ the vowels for the unknown, and the consonants for the known quantities. This is in itself a matter perfectly arbitrary, and, provided it is adhered to, either method of distinguishing known from unknown quantities is equally proper; but whenever one of these, suppose that now in use, is fixed upon for this purpose, if we wish to consider known and unknown functions, and to treat of their relations, it is no longer a matter of indifference how they are to be distinguished. The rule we are now illustrating must be attended to, and if we have used the first letters of the alphabet for known quantities, it compels us to employ the first letters of whatever other alphabet we may fix on to indicate functions for the known ones, and the latter letters of the same alphabet for the unknown ones. Thus, if a, b, c, &c. are known quantities, and x, y, z, &c. unknown ones, α, β, γ, &c. must denote known functions, and ϕ, χ, ψ unknown ones. In another instance, the repetition of a letter xx has been marked thus x^2. Analogy, therefore, would direct us when we wish to repeat an operation as $\psi\psi$, to contract it by writing it thus, ψ^2, and similarly for others, as ψ^3, ψ^4.

We have already had occasion to remark, that we ought not *to multiply the number of mathematical symbols without necessity.* This is a maxim of so much importance that it deserves a fuller consideration.

The natural tendency of the science is to develop new relations and new combinations of those already known. When these new relations involve complicated combinations of such as are already received, or when they are of frequent occurrence, it becomes necessary, if it were merely for the sake of brevity, that some new symbol should be employed; it is, however, a necessity that ought to be avoided as much as possible; and the rule is one which has suffered many infractions in modern times. Amongst the numberless instances may be remarked the case of a function consisting of the product of a number of terms in arithmetical progression. This species of function is of some importance, and has been frequently considered, yet scarcely any two authors have agreed in the notation they have employed. The first, in point of time, is that of Vandermonde. (*Acad. des Sciences,* 1779.) He expressed the quantity, $x.x-a.x-2a\ldots x-\overline{n-1}a$ by the sign $[x,a]^n$, or when $a=1$, more shortly, thus $[x]^n$. Kramp, in his treatise on *Astronomical Refractions,*[*] calls the functions in question *facultées numeriques*, and denotes them thus $x^{n\mathrm{I}a}=x.x+a\ldots x+\overline{n-1}a$. Arbogast has occasion to treat of the same quantities,[†] when he represents thus $\mathrm{D}^n 1^x = x.x-1\ldots x-\overline{n-1}$.

Legendre, in his *Exercises du Calcul Integral,* employs a different notation to express a function very nearly allied to that we are considering. He denotes $x.x-1\ldots 2.1$ by $\gamma(x)$. Euler also treated of the properties of the co-efficients of a binomial, and denoted them by the characters $\left(\frac{n}{1}\right)$, $\left(\frac{n}{2}\right)$, $\left(\frac{n}{3}\right)$, &c. Of these various methods of denoting the same thing, that of Vandermonde seems to be the most advantageous. The reasons of this preference we shall shortly state. When x is repeated n times, $x.x\ldots x$, it is represented by x^n; and generally, when any letter denoting either operation or quantity is repeated, it has the letter indicating the number of repetitions placed in the right hand corner above it; such is the case in the following instances, x^n, d^n, δ^n, f^n. It is therefore correct, as far as regards analogy, to place the index in that situation; so far then as relates to the position of the letter n, both the notations of Vandermonde and that of Arbogast are equally admissible; this, however, is not the case with the letter a. It is used for the difference of two successive factors, and has no regard at all to repetition; it is not therefore consistent with analogy to place it in a similar situation.

Another, and a very powerful reason for preferring the system of Vandermonde is, that it admits of unlimited extension, without in the least infringing on typographical facility. When the factors have their second difference zero, they are denoted thus:

$$\left[x,\,a\right]^{n} = x.x-a\ldots x-\overline{n-1}.a$$

M. Lacroix has assigned to such expressions the appropriate name of powers of the second order. If the third differences are zero, they are called powers of the third order, and are readily denoted thus:

$$\left[x,\,a,\,b,\right]^{n} = \text{ⓧ}\ \overline{x+a}\,.\,\overline{x+2a+b}\ldots\overline{x+n\,a+\frac{n\cdot\overline{n-1}.b}{2}}$$

and similarly for the higher orders: this notation therefore admits of a very easy extension to complicated cases, without increasing its difficulty of execution. Perhaps it may be urged that the notation of M. Kramp may be extended as follows:

$$x^{n\,\mathrm{I}\,a,\,b} = x\,.\,\overline{x-a}\,.\,\overline{x-2\,a-b}\ldots\overline{x-n\,a-\frac{n.n-1}{2}b}$$

but the difficulties of the printer will be greatly increased the moment any substitutions are made for a or b, and the other objections remain the same.

These inconveniences attend the method of Arbogast in at least an equal degree. That which Euler has employed is adapted to the particular purpose he has in view; but if it be allowed that sufficient reasons have been produced to justify the preference we have assigned to that of Vandermonde, it is highly desirable that it should be employed on all future occasions. We have observed that M Legendre uses $\gamma(x)$ to represent $x\, x - 1 \ldots 2.1$, whether x is a whole number or a fraction; this can scarcely be termed a new notation; but it is certainly rather to be regretted, that so able an inquirer should not have given his sanction to a notation previously established, and which agrees so well with those rules on which all notation should be founded.

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[*] Strasburg, 1798.

[†] Calcul des Derivations, 1800.

The two signs which denote differentiation and integration are, in strictness, liable to the objections of this rule; and a similar remark is applicable to the similarly related signs Δ and Σ.

In several of these instances, mathematical signs have been needlessly multiplied by not attending to this principle, that *whenever we wish to denote the inverse of any operation, we must use the same characteristic with the index* -1. This principle being acknowledged, we shall in future be delivered from one cause of the redundancies of signs. Should, for example, any future inquirer, when considering the calculus of variations, have occasion for the inverse operation of that denoted by δ, he must not, conformably to a hasty view of analogy, represent it by σ; but, directing his attention more deeply to the subject, he will perceive the necessity of indicating it by δ^{-1}

Again, in the equation $x = \tan y$, the value of y, in terms of x is usually expressed $y = \text{arc} \tan x$; this is both long and inelegant. It should, in complying with the rule just laid down, be written thus: $y = \tan^{-1} x$, and similarly with other circular functions; this method is likewise attended with the advantage, that all this class of functions will then be indicated by three letters.

Another principle, whose importance becomes eminent in proportion as our investigations become general, is, *that every equation ought to be capable of indicating a law.* Signs must not be employed at random, nor must new ones be introduced without grave necessity. When, however, unusual combinations, or the demonstration of new properties, render such a resource indispensable, it becomes particularly desirable that those which are first contrived, should be possessed of such propriety and power as shall effectually preclude future innovators from all temptation to change them. Analogy to those which form the established language of the science, although a precept of great importance, cannot be admitted to supersede the rigid enforcement of that we are now considering: happily, however, the two principles will rarely be found at variance, for those symbols, and those inflexions of symbols, (if the term may be allowed,) which long experience has naturalized, generally furnish the most correct models of imitation. A precept in some measure connected with this principle, although it may perhaps be considered of minor importance, may be introduced.

In case it is required to express a series continued to n terms, the nth term should be written, and not the words "to n terms" be attached to a few of the first. These different methods would appear thus:

$$y = \frac{1}{1} + \frac{1}{2} + \frac{1}{3} +, \text{ to } n \text{ terms.}$$

$$y = \frac{1}{1} + \frac{1}{2} + \frac{1}{3} \ldots + \frac{1}{n}.$$

In this simple case, something is gained in point of brevity; and if deductions are to be made from it, much is gained in perspicuity. The justice of this observation will be more readily acknowledged if it is put into rather different language. Its object may be thus stated: *It is better to make any expression an apparent function of* n, *than to let it consist of operations* n *times repeated.* Thus, if it is required to express the series

$$\frac{1}{1^n} + \frac{1}{2^n} + \frac{1}{3^n} + \ldots$$

By means of a definite integral, its value would be

$$\int \frac{\mathrm{d}\,x}{x} \int \frac{\mathrm{d}\,x}{x} \,.\, (n) \int \frac{\mathrm{d}\,x}{1-x} \qquad \left[\begin{matrix} x=0 \\ x=1 \end{matrix}\right]$$

Where there are n integrations; or as it has been written by Mr. Spence,

$$\int \frac{\mathrm{d}\,x}{x} \int \frac{\mathrm{d}\,x}{x} \ldots \int \frac{\mathrm{d}\,x}{1-x} \qquad \left[\begin{matrix} x=0 \\ x=1 \end{matrix}\right]$$

Neither of these methods possess that clearness which ought instantly to convey to the mind the system of operations intended to be expressed; for it does not appear quite certain whether the n means that there are n repetitions of $\int \frac{\mathrm{d}\,x}{x}$, or that the whole number of integrations is n: this latter is the signification in which it is employed by Spence. A better method of expressing it would be,

$$\left(\int \frac{1}{x}\right)^n \frac{x}{1-x} \mathrm{d}\, x^n, \text{ or } \left(\mathrm{d}^{-1} \frac{1}{x}\right)^n \frac{x}{1-x} \mathrm{d}\, x^n$$

To any one acquainted with the integral calculus, this could not convey an incorrect idea, although presented for the first time, and without explanation. The index n denoting the repetition of the quantity to which it is attached, gives

$$\int \frac{1}{x} \int \frac{1}{x} \ldots \int \frac{1}{x} \frac{x}{1-x} \mathrm{d}\, x^n.$$

And it is clear that the $n\ d\ x\ s$ must be assigned to the n integrations. This latter expression may indeed be employed as deviating still less from the received one, and as still less liable to misinterpretation.

Another principle, which is chiefly valuable as it conduces to brevity, is, *That all notation should be so contrived as to have its parts capable of being employed separately.* By observing this rule, we avoid being encumbered with any other signs than those actually necessary to express the properties we are considering. This principle has been so universally followed, that it is difficult to produce examples of its neglect. Thus, although it has never been expressly proposed in terms, it has been virtually acted upon by analysts for the last two centuries.

It was in fact to be expected, before any general principles of notation were delivered, that it should be extended in exact proportion to the progress of the inquirer, and this progress proceeding from the simple to the more complicated, his notation would naturally increase by continued additions. Such being its origin, it will necessarily follow, that at any stage it might be used without reference to those additions with which subsequent considerations had obliged him to augment it.

It is a valuable service rendered to any science, to embody into language those rules which perhaps insensibly direct or govern the minds of those who improve it; however apparently obvious some of them may be, or however well known amongst the instructed, a considerable time will always elapse before individual penetration will have formed for itself such guides; nor will the advantage be entirely confined to the student. How frequently does it happen, even to the best informed, that they prefer one thing and reject another, from some latent sense of their propriety or impropriety, without being immediately able to state the reasons on which such choice is founded; yet it cannot be doubted, when the selection appears to be the result of correct taste, that it is guided by unwritten rules, themselves the valued offspring of long experience. Any explanation of these is probably rendered unavailing at the instant, for want of having previously fixed them by language.

Another reason which appears to justify, or rather to oblige us to notice this principle, is, that although it has not hitherto been much infringed, it seems probable that, unless due care be taken in the future formation of notation, some of the rules which have been proposed may themselves lead to its infraction. This observation more particularly applies to that which directs us "to contrive all notation, so that it shall be capable of expressing laws." In attempting to satisfy this condition, we are obliged to take wide and extensive views, and are therefore peculiarly liable to forget that which may appear of minor importance. The two principles are by no means incompatible; and it is very desirable that when we have occasion to employ the latter, the former may always be borne in mind.

Having discussed the general principles on which notation should be formed, it now becomes necessary to explain several rules which are proposed for the proper application of individual signs. Writers on algebra have defined the meaning of the signs they use; but something further than these definitions is requisite in the present state of the science, or, to speak more accurately, some limitations, as well as extensions of the meaning of several of them, are required.

There are in analysis two great divisions of symbols, —those which denote quantity, and those which indicate operations. These latter were all of them originially arbitrary marks, such as those employed to express addition, multiplication, &c. At the present time, however, letters are frequently employed to signify operations, and hence arises occasionally a source, if not of error, at least of inconvenience. The use of letters in two senses has been objected to the followers of Leibnitz, who employ the *d* to denote the differential of the quantity to which it is prefixed; and as differentials are much employed in the doctrine of series, it sometimes occurs that the fourth term of the series $a + b\,x + c\,x^2 + d\,x^3 +$, enters into calculations in which the *d* also represents an operation performed on the letter to which it is prefixed. This inconvenience has been avoided by M. Lacroix, who uses the Roman d for differentiation, and the Italic *d* for quantity. Arbogast also, in his work on Derivations, employs the Roman d for the same purpose. This completely removes the inconvenience; but in order to prevent its recurrence in any other shape, and for the purpose of affording a wider choice in the selection of letters, we would propose the following general rule: *All letters that denote quantity should be printed in Italics, but all those which indicate operations should be printed in a Roman character.* Thus the letters x, y, z, . . a, b, c, . . α, β, . . ψ, θ, would represent quantity; and, d, f, A, B, C, would denote operations. The only inconvenience which would attend this method, is of very minor importance: it would become necessary to cast new types for a few of the Greek letters in common use, because the difference between those two modes of printing does not exist in that language.

The class of letters that are termed characteristics, and which represent operations, is divided into two species; those which denote functions, as

$$\mathrm{f},\ \mathrm{F},\ \varphi,\ \psi,\ \chi,$$

and those which signify that some alteration is to be made, which depends on the nature of the function on which it is to be executed: thus $f\ (1 + x^2)$ means a function of $1 + x^2$. In this case the form of the function selected for f is quite independent on $1 + x^2$; but if we have $\mathrm{d}\ (1 + x^2)$ the effect of the operation denoted by d, depends on the form of the function inclosed within the parenthesis: this is the case with the symbols

$$\mathrm{d},\quad \int,\quad \Delta,\quad \Sigma,\quad \mathrm{S},\quad \delta.$$

Those of the former species are called *functional characteristics;* and as it will be convenient to have some generic name for the latter, we shall appropriate to them that of Derivative Characteristics, since their own form depends on, and is derived from that which follows them.

The first of these species is subject to the following rule: *Every functional characteristic affects all symbols which follow it, just as if they constituted one letter.*

Thus, if $\alpha\,x = a\,x + b\,x^2$, and $f\,x = 1 - x^2$,
Then, $\alpha\,f\,x = \alpha\,(1 - x^2) = a\,(1 - x^2) + b\,(1 - x^2)^2$
And $f\,\alpha\,x = 1 - (\alpha\,x)^2 = 1 - (a\,x + b\,x^2)^2$.

Two signs have been made use of to represent multiplication: the cross (×) and the dot (.); and the simple juxtaposition of two letters, if they are in Italic, means the same thing: this last method is preferable in all simple cases, as

$$a\,b\,c,\quad x^2 y\qquad \frac{a + x}{y}\,a^2$$

There exists a difference of meaning between the two former of these methods of indicating multiplication and the latter, which it is necessary to explain, and to which it is convenient to adhere. The dot and the cross imply a kind of disjunctive multiplication, or that, when they are interposed between two quantities before which a derivative characteristic is placed, this symbol only applies to the first of the two:

As, $$\Delta\,\frac{x + a}{x}.\ \ \frac{\epsilon^x - 1}{x}$$

which represents $$\frac{\epsilon^x - 1}{x}\,\Delta\,\frac{x + a}{x}$$

If the dot or cross were not used in this case, the meaning would be quite different, for $\Delta\,\dfrac{x + a}{x}\ \dfrac{\epsilon^x - 1}{x}$ would signify the complete difference of the quantity $\dfrac{x + a}{x^2}\,(\epsilon^x - 1.)$

Another common signification of the dot is, that when it is placed immediately after a derivative characteristic, it implies that the derivation extends until some other dot occurs which may separate it from any succeeding factors: This is sometimes denoted by brackets of various kinds, thus,

$$\mathrm{d}.\, xv.\ \frac{\mathrm{d}u}{\mathrm{d}x}$$

denotes the differential of u relative to x, multiplied by the complete differential of xv. If written thus,

$$\mathrm{d}.\, xv\ \frac{\mathrm{d}u}{\mathrm{d}x}$$

it would signify the complete differential of $xv\ \frac{\mathrm{d}u}{\mathrm{d}x}$.

In the operations of the differential calculus, it is constantly required to express the second and higher powers of a differential, as $(\mathrm{d}\,x)^2$, $(\mathrm{d}\,x)^3$, $(\mathrm{d}\,x)^n$, whilst it has rarely been found necessary to express the differentials of the simple powers $\mathrm{d}\,(x^2)$, $\mathrm{d}\,(x^3)$, .. $\mathrm{d}\,(x^4)$. These two series differ in the situation of the parentheses they contain; but as the quantities in the first recur perpetually, it was desirable that they should be contracted by omitting the parentheses. Universal usage has sanctioned this omission, and they are always written thus, $\mathrm{d}\,x^2$, $\mathrm{d}\,x^3$, . . $\mathrm{d}\,x^n$; and in order to remove the ambiguity which this might occasion, in the few cases where the quantities mentioned in the latter series occur, they are distinguished by means of the point thus, $\mathrm{d}.\,x^2$, $\mathrm{d}.\,x^3$, . . $\mathrm{d}.\,x^n$.

The principle that *parentheses may be omitted, if it can be done without introducing ambiguity*, has been partly adopted in the manner of expressing circular functions; a department of analysis in which the inattention to all general principles of notation has been severely felt. Five methods have been generally employed for expressing the squares and higher powers of the sines and cosines of arcs.

$$(\sin.\,\theta)^2,\ \sin.\,\theta^2,\ \sin.\,{}^2\theta,\ (\sin\theta)^2,\ \sin\theta^2.$$

The first of these has nothing objectionable in it except the dot, which is not merely useless, but interferes with another principle. The second omits the parentheses, in compliance with the principle we have just stated: like the former, it has the useless appendage of the dot. The third is by far the most objectionable of any, and is completely at variance with strong analogies. An index, in the situation in which it there occurs, invariably denotes repetition of the symbol to which it is attached: in this case it would therefore mean sin. sin. θ, or the sine of the sine of the arc θ. It is true that this notation may be defined to mean the square of the sine, or any other function of the sine. Although a definition cannot be false, it may be improper; and the impropriety may arise either from its inducing ambiguity, or from its offending against received principles; both which objections occur in the present instance. Besides, if sin ${}^2\theta$ were allowed to signify the square of the sine of θ, how should we denote the second sine of θ? It may safely be asserted, that if this notation for the square of the sine were admitted, no convenient method could be devised, which should not also infringe some general principle. Thus one infraction would become the ground of introducing another, and instead of possessing a philosophical language founded on general laws, the science would arrive at one with no regularity to assist the memory, and devoid of those strong analogies which facilitate the acquisition of all others.—The fifth method, $(\sin\theta)^2$, is made use of by Arbogast, in his work on the Calculus of Derivations; an authority which is entitled to the greater weight, because, from the nature of that excellent work, and the powerful use which is made of the various notations employed in it, it is highly improbable that the author should have selected this out of the many received notations, without having well considered its propriety. It differs but little from the last method, the parentheses only being omitted, which gives $\sin\theta^2$ a mode of expression sufficiently clear for all simple cases. If, however, θ become a compound quantity, the parentheses must again be introduced. This notation has been employed by M. Lacroix, in his great work on the Integral Calculus. M. Gauss and Delambre have also adopted it; and it is likewise used in the latest and most valuable work of Lagrange.*

In order to connect together various symbols which compose part of an expression, and which are subjected to the same operation, different species of vincula† are employed. From the great variety of these which are used by the printer, a considerable latitude of choice is allowed. In genenal, all symbols collected under a vinculum are to be considered and operated upon, as if they formed a single symbol. The choice of parentheses, although a matter of minor importance, is not altogether arbitrary. An example, in which propriety and impropriety are apparent in different modes of writing the same expression, will be sufficient without the aid of formal rules.

$$\left[1 - \left(\tan\frac{a}{y}\right)^2\right]^2 + \left\{1 - \left\{\tan\frac{y}{a}\right\}^2\right\}^2$$

$$\left(1 - \left[\tan\frac{a}{y}\right]^2\right)^3 + \left(1 - \left\{\tan\frac{y}{a}\right\}^2\right)^2$$

$$\left\{1 - \left(\tan\frac{a}{y}\right)^2\right\}^2 + \left\{1 - \left(\tan\frac{y}{a}\right)^2\right\}^2$$

Of these three ways of writing the expression, the last is evidently to be preferred: the other two are objectionable, not from any deficiency in clearness, but from a certain want of symmetry, which is very perceptible in both of them.

Modern analysts have frequently had occasion to separate the symbols of operation from the quantities on which they act, an artifice which gives great conciseness to a variety of theorems: this separation has been marked in different ways, either by a dot, or the sign of multiplication, or by parentheses: in some instances the double dot (:) has been employed. As it is very desirable to confine each symbol to one meaning, the last plan, or the two dots, is the least objectionable for this purpose, and can create no ambiguity, since it has become entirely obsolete in the best writers in any other sense. The theorems of Lagrange would be thus written.

$$\Delta^n u = \left\{ \epsilon^{\frac{\mathrm{d}}{\mathrm{d}x}} - 1 \right\}^n : u, \qquad \Sigma^n u = \left\{ \epsilon^{\frac{\mathrm{d}}{\mathrm{d}x}} - 1 \right\} : u.$$

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* Mecanique Analytique.

† Such as braces, parentheses, brackets, bars, &c.

The merits of the two systems of notation employed in the differential calculus have been discussed by Euler, in the preface to his Institutiones Calculi Integralis, and more fully by Mr. Woodhouse, in the preface to the Analytical Calculations. The superiority of the use of the d over the system of dots has become so very apparent, that the course of a few years will, in all probability, render the latter obsolete, a circumstance which induces us to forbear entering into any lengthened detail of their comparative values, and to content ourselves with merely indicating a few of the grounds for rejecting the latter: these are, 1st, The uncertainty which may arise respecting the letters to which the indices refer, and the confusion which arises from having two indices to a letter. 2d. The want of analogy with other established notations, such as those relating to the symbols Δ and δ. 3d, The great difficulty, if not the impossibility, of representing, by their means, theorems relating to the separation of operations from quantities.[*]

NOTTAWAY, a county of Virginia, bounded east by Dinwiddie, south by Brunswick, and Lunenburg or Nottaway river; north-west by Prince Edward; and north-east by Amelia. Length, 22; mean width, 12; and area 264 square miles. It is watered by some branches of the Appomattox, and by the Nottaway and its branches. Staples, cotton and tobacco. The chief town, Hendersonville, is 45 miles south-west by west from Petersburg.

Population in 1810.

Free white males	1,380
do. do. females	1,350
Total whites	2,730
All other persons except Indians not taxed	180
Slaves	6,368
Total population in 1810	9,278

Population in 1820.

Free white males	1,386
do. do females	1,419
All other persons except Indians not taxed	2
Total whites	2,807
Free persons of colour, males	71
do. do. females,	104
Slaves, males	3,314
Do. females	3,362
Total population in 1820	9,658
Of these;	
Foreigners not naturalized	1
Engaged in Agriculture	3,170
do. in Manufactures	238
do. in Commerce	12
Population to the square mile,	36

NOTTAWAY, a river of Virginia, rising in the south-east angle of Prince Edward county, Virginia, and flowing south-east by east, joins Black river branch of Chowan, on the northern border of North Carolina, after a comparative course of 130 miles. DARBY.

NOTTINGHAM. Few towns occupy a more commanding, and, at the same time, delightful situation, than this large and respectable capital of the shire to which it gives name. Spreading over the swift declivity, partially along the base, but very principally over the level summit, of a terrace-like eminence, that here rises from the rich vale of Trent, and fronts the south, Nottingham greets the eye of strangers approaching from the southern districts of England, with a prospect of equal dignity and beauty. When sufficiently near, they see, in the foreground, besides a bridge across the smaller river Lene, which runs close in beneath the town, a large and noble bridge of twenty arches, across the full stream already named as that which laves the vale; they behold, on the west of the compact body of houses that on the east decline gradually into the plain, a stately modern chateau, (the castle,) proudly seated on the point of an inland promontory; and view, rising from the town itself, a church, that, in form, magnitude, and architecture, might vie with many cathedrals. If, on a close approach, the redness of the brick which composes, and of the tiles that roof the houses of Nottingham, impress somewhat unfavourably the eye, let the town be entered, and its general neatness, the elegance of some of its parts, its clean appearance, and the air of comfort diffused almost throughout, will change that impression into one highly advantageous to the place, which really merits to be be regarded as a kind of provincial metropolis.

Its name is the ancient Saxon one of *Snottingaham*,[†] slightly altered, but very palpably improved; a name derived, it is said, from excavations made in the sides of those soft rocky eminences that distinguish the site, and which were occupied as dwelling places by some of the aborigines of England, from perhaps a very remote period. In attempting to establish the origin of Nottingham, conjecture has oft indulged her wildest mood. Ebranc, fifth king of the Trojano-British dynasty, and whose reign is said to have commenced 1030 years before Christ, has been named as its founder; although much more modestly it has been said to be proved to have then existed as a town, by being chosen for the burial place of Coilus, the last of the pagan kings of Britain, and reported founder of the town of Colchester. Dismissing these idle tales, and passing over other legends respecting the ante-christian and early Christian period of the history of Nottingham, as equally undeserving of serious notice, it may be remarked, that reasons not devoid of plausibility have been urged in favour of a conclusion formed by some antiquaries; viz. that here was the Roman Causennis, a station given in the Itinerary of Antoninus, as that between Durobrivis, now Brig Casterton, and Lindum, the present Lincoln. Descending upon the annals of the Saxon period, we find it generally, nay, universally allowed, that the place had become considerable; and was even defended by a tower or fort. It kept advancing, and, as we learn from Domesday-book, had, in the time of the Confessor, 173 burgesses, and 19 villeins, resident within it. Like almost every other place of that early consequence, Nottingham suffered from the Norman invader's merciless severity. When the Domesday Survey was made, only 120 resident householders were found in the place. This depression was, however, probably short-lived, as the burgesses seem to have possessed at the time very considerable privileges; of the chief of which, viz. the proprietary and occupation, as a body, of six carucats, each carucat being about 120 acres of land, to plough, besides pasture and meadow in proportionable quantity, with barns, stables, and dwellings, correspondent, they do not appear to have been deprived by William. The great prosperity of Nottingham is, nevertheless, to be referred to modern times: although, as the slight sketch of its annals subjoined to this article, will show, it has from an early period, occupied a prominent place among the more distinguished towns of England.

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[*] The editor has been indebted for this interesting article to CHARLES BABBAGE, Esq. F. R. S. Lond. and Edin.

[†] From *Snottinga*, cave, and *ham*, a dwelling, or dwelling house.

Its position is almost in the centre of England, but in the south-eastern part of the county to which it gives name. It stands on the northern bank of the river Lene, about a mile north of the river Trent, into which, a little to the north-eastward of the Trent bridge, the Lene flows: at the southern point of the great forest of Sherwood, so celebrated for the exploits of Robin Hood and Little John, and at the distance of 124 miles north of London—the great mail-coach road from which, to Sheffield and Leeds, passes through the town. In every direction, except, perhaps, just upon the forest line of road, the surrounding country is rich, populous, and beautiful; were it not that the inclination towards the east is more gradual, and the abruptly terminating rock on the west, "Dolorous Hill," is said to have been the appellation borne by the eminence on which Nottingham stands; an appellation derived, say the same veracious chroniclers, from the grief of the surviving Britons over an excessive slaughter made of their countrymen by a king, Humber, from the north. Less elevated, the situation of Nottingham would greatly resemble that of Edinburgh; only, if any one would avail himself of this remark to form a more correct idea of the site of the former, he must be careful to remember that at Nottingham there is no North Loch, but the town is continued northward on a uniform, although very gentle ascent, till it is terminated by a second rather abrupt elevation, parallel with that which overhangs the Lene. The rock on which it so airily stands, is a dry, soft one, overspread with a light sandy soil. Much of the town, however, to the production of many singular and pleasing prospects, is built on the front, and along the base of the lengthened hill that ascends from the vale of the Trent and Lene; a vast extent of which vale, smiling in cultivation, studded with villages, and adorned by villas, is commanded from the edge of the hill. The streets of Nottingham are many in number, and some of them of considerable length; narrowness is, however, characteristic of most of them. Castle-gate, and the High Pavement, form an exception to this last remark; and the market-place, whether we consider the extent of its area, or the appearance of the buildings that range around it, may well claim the epithet of noble. Leland, despising English grammar, calls it "the most fairest without exception of all England;" and Moritz, a German traveller, accustomed to the splendours of Berlin, writing, in his account of a pedestrian excursion that he made to the Peak cavern, a description of the town, is in raptures with its market-place. Of the caves, or cavernous habitations of Nottingham, mention has been already made. Sneinton, a suburban village, contains many of them; with the singular appearance of which, the stranger entering the town from the north will be much struck. According to some, indeed, the greater part of Nottingham stands on ground excavated into rooms and subterraneous passages; and it is certain that, so long ago as the time of Leland, many caves were used as cellars and storehouses. Of some remarkable ones, mention will yet fall to be made in our article.

The charitable institutions of Nottingham are numerous, and, speaking generally, of an important character. Plumptre's Hospital, an interesting edifice, originally founded in the reign of Richard the Second, for two chaplains, one of whom was to be master, and 13 poor widows; but since augmented by two descendants of the founder, John Plumptre, is situated at the bridge end. Fifteen shillings a-month, with a ton of coals, and a gown annually, are received by each pensioner. Collins's Hospital, in Friar Lane, founded in 1704, has also claims to notice as a building. It is for twenty-four poor men and women, who are comfortably lodged, provided with fuel, and receive each 2*s.* a-week. Besides these, and similar to them in their objects, are Willoughby's, Gregory's, Handley's, the Labourers', Warsargate, &c. hospitals; Woolley's Beadhouse; Beilby's almshouses; the Peckham and Coventry Charities, &c. In each parish, moreover, there is a workhouse for the general poor. The General Infirmary is a noble charity, and fine building. It was founded in 1781; stands in the midst of an agreeable garden and airing grounds; exhibits a centre, two projecting wings, and two extreme projections; has recently been enlarged very considerably; it has been, is, and in all probability will be, of most essential and extensive use. In addition to numerous exceedingly liberal benefactions, it deserves to be recorded, that one individual, long unknown, but since discovered to have been the late Reverend Thomas Gisborne, author of sermons, poems, &c. subscribed to the Nottingham General Infirmary at once 10,000*l.* stock, a sum equal to 6,337*l.* Sterling. He bestowed, at the same time, a like sum on two other infirmaries, viz. on that of Sheffield, and, we think, that of Leeds. Another charitable establishment, on a very extensive scale, is the Lunatic Asylum. Its benefits are extended to paupers, as well as to those whose circumstances, or those of their friends, permit a board to be paid for them. This edifice, a large one of five stories, including two basement ones, in height, is, although but a very little way out of the town, in the chapelry of Sneinton. Great liberality has been evinced in contributing towards its establishment and support. It was opened in 1812.

Among the institutions which have education for their object, we place first the free Grammar School, which was founded in 1513 by Agnes Mellors, widow of an opulent bell-founder of Nottingham. This is really a *free* school, for, by a corporation act made in 1807, sixty boys are admitted upon the foundation, and gratuitously taught, or may be taught, Greek, Latin, English, writing, and arithmetic. In the High Pavement is a charity-school for fifty poor children of both sexes, forty of whom are clad in blue uniform, and to all of whom instruction is dispensed in the principles of Christianity, and in English reading. Two other charity-schools, both in St. Mary's parish, afford the means of instruction to thirty, and sixteen poor children respectively. Clothing and a plain education are given to poor children among the Protestant dissenters, in an establishment of their own. A national school, and a Church of England Sunday school, are also among the educational establishments of this flourishing town; while, in the other numerous Sunday schools of the place, not fewer, it is computed, than

3000 children are, in a measure at least, and gratuitously, instructed.

Of the market-place mention has been already made. There is a handsome and highly useful building connected with it, which, although built about a century ago, is called the New Exchange. It is constructed of brick, is four stories high, and has an open corridor or piazza beneath it. Justice, in sculpture, poising her scales, and wearing over her eyes the symbolical bandage, crowns the pile; partly on the ground-floor of which, and partly behind it, are the shambles. Rooms in which different corporation business is transacted, are, as well as a subscription news-room, termed the Exchange Hall, contained in the building. That the markets of Nottingham, although, like those of most manufacturing towns, somewhat high as to prices, are variously and abundantly supplied, it is almost superfluous to remark. As an appropriate symptom of the celebrity of this town for ale, it may be observed that the malt-cross, one of several crosses, such as the work-day cross, &c. now demolished, once stood at the higher end of the market-place. The market days are Wednesday and Saturday. On these days also, but only on the first of them in this market-place, an ancient cattle market is held. Three fairs are held annually, viz. on the 7th of March, the 2d and 3d of April, and the 2d of October, the last being a nine-days' fair.

For the amusement of the inhabitants, a neat theatre, situated in St. Mary's Gate, an assembly room, a riding school, (this, being that of they eomanry cavalry, is only occasionally used as a circus by itinerant equestrians,) and annual races, held in July, make provision. The race-course, belonging to which is an elegant stand, is to the north of the town, adjoining on the east to the Mansfield road. Walks in great variety, and affording delightful prospects, are also among those appendages of which relaxation is a principal object.

As a manufacturing town, Nottingham has long ranked high. The making of malt seems to have been begun soon after the Norman conquest, and is yet extensively carried on. Till the reign of Queen Mary the making of coloured cloths was briskly prosecuted here, but from her time it declined, and has fallen away almost entirely. Nottingham is, however, a principal seat of the manufacture of hosiery, especially of silk and cotton stockings. It is nevertheless, remarkable, that, in the year 1641, there were in the place only two frame work knitters. The machine now made use of, originally invented by William Lee, in the reign of Elizabeth, is characterized by equal simplicity and utility; and the quantity of goods produced is very great, both for the home and foreign markets. Industry, thus directed, pervades, not the town only, but the surrounding country, and has even spread itself to distant places: such, for instance, as Leicester. So long ago even as the middle of last century, 1200 frames were at work in Nottingham alone, a number now, doubtless, greatly increased; especially as the trade is understood to be at present in a flourishing state.

The making of bone lace, as it was termed, has declined, but that of frame lace has been introduced, and is extensively carried on. Of patent net all have heard, and it is chiefly made at Nottingham. Mills for spinning and twisting both silk and cotton are in considerable number. Tanning, once so great a trade here as to have spread vats over almost all the town, in which, in 1641, there were forty-seven master tanners, has greatly fallen off; although it is not totally gone. The making of glass has ceased, and the earthenware manufacture is of small account. That of white lead is carried on. Cast-iron goods are also fabricated. Dyeing is not quite extinct; bleaching is one of the branches of industry exercised; brewing also gives employment to a number of persons; and in the general shop-keeping line, Nottingham, to the trade of which at least two Banks, the Trent Navigation, and sundry vicinal canals, afford great facilities, has the supply of a pretty extensive surrounding tract, thickly strewn with populous villages. Under these favourable circumstances, the population of the town has kept steadily increasing for many years. In 1739, the number of inhabitants was 10,010; in 1751, 10,061; in 1779, 17,711; in 1801, 28.661; and in 1811, 34,363. See Thornton's *Notes, republished with additions by* Throsby; Deering's *Nottinghamia, vetus et nova;* Leland's *Itinerary; the Beauties of England and Wales*, vol. xv. &c. (*v. v.*)

NOTTINGHAMSHIRE, one of the internal counties of England, extends from 52° 50′ to 53° 34′ of north latitude, and from 0° 35′ to 1° 14′ of west longitude. It is bounded on the north by Yorkshire, on the east by Lincolnshire, on the south by Leicestershire, and on the west by Derbyshire. In shape it resembles an oval, gradually tapering towards the north, where, for a number of miles, it is extremely narrow. The greatest length is 50 miles, the greatest breadth 27, the medium breadth about 16; the circumference measures above 140 miles; the area is estimated at 837 square miles, or 535,680 acres. It is divided into 6 hundreds, which include 160 parishes; the number of market-towns being 9, and of villages or hamlets 450. It lies in the diocess of York, and sends 8 members to Parliament.

In its external aspect this county presents an agreeable inequality of surface, intermediate in character as in situation, between the mountains of Derby and the flats of Lincoln. It is generally covered with rich verdure, copiously sprinkled with trees, contains abundance of streams, and its varied scenery is enlivened by numerous mansions and cheerful farm-houses. A ridge of high ground extends from Nottingham north-eastward to the extremity of the county, where it terminates abruptly, and appears in the eyes of some speculative geographers to have once formed the shore of a sea, which in those distant ages yet overflowed the surrounding fens. The southern portion of the county exhibits the contrast between the beautiful vale of Belvoir and the *Wolds*, a chain of bleak hills generally uninclosed, or but partially beginning to be covered with wood.

Of the rivers of this county, by far the largest and most important in every point of view is the Trent, which rises near Biddulph, in the moorlands of Staffordshire; descends from the hills in a rapid current, augmented by numerous rivulets from Cheshire and Lancashire; enters Nottinghamshire near Radcliffe-upon-Soar; passes the county town; proceeds by a slow tortuous course through a highly cultivated country to Newark, where it suddenly takes a bend towards the north; leaves the county at Heck Dyke; and at length falls into the Humber, after a course of nearly two hundred miles. It loses the influence of the tide at Gainsborough, about eight miles above Heck Dyke, and is no longer navigable for ships of any great burden; but vessels of a flatter construction are constantly occupied in it as far as Burton in Derbyshire. The Trent canal, a side cut of ten miles, enables those boats to avoid the only shoals, (twenty-one in number, which occur in its course. The Soar, the Erewash, the Idle, the Lene, are branches of the Trent, but present little worthy of notice.

Nottinghamshire is distinguished for the salubrity of its climate, and especially for its dryness. The Derbyshire hills serve as a rampart against the clouds proceeding from the west, and rapidly attract those arising from the east. At an average, little more than 20 inches of rain falls in this county during the year; a comparative lowness of level contributes to augment the warmth arising from this extraordinary absence of moisture; and it is remarked, that seed-time and harvest occur almost as early here as in the most southern districts of the kingdom.

In regard to the qualities of its soil, this county is divided into four principal districts; the district of coal and limestone; that of sand and gravel; that of clay; and that along the banks of the Trent. The first of these divisions forms a narrow stripe of land contiguous to the borders of Derbyshire, and extending from the latitude of Worksop to that of Nottingham, with a medium breadth of about two miles, the broadest part being towards the south. It is chiefly arable, and contains several woods. The second district, that of sand and gravel, runs parallel to the former, but is much longer and broader, stretching from Nottingham by Worksop and Bawtry, quite up to the northern boundary of the county, where it occupies the whole extent of it from the Trent westward. Its length is about 34 miles by a medium breadth of seven: it includes the whole of the ancient forest of Sherwood. The third, or clay district, is again subdivided into two—the north clay, and the south clay: the former extends from Nottingham by Taxford to a little below Gainsborough in Lincolnshire, the length being about 34 miles, the average breadth about five; it is bounded on the west by the preceding, or sand and gravel district, and constitutes the most fertile portion of the county, owing in part to a considerable intermixture of sand, which renders the mould more friable and fitted for agricultural labour than clay lands usually are. The south clay subdivision reaches from Newark to the borders of Leicestershire, a length of 20 miles, with a medium breadth of five: it includes the vale of Belvoir, or Beever, and the Wolds. It is separated from the north clay subdivision by the fourth principal district, that of Trent-bank, which extends along both shores of the river during the whole of its course through the county, the length being 30 miles, the breadth varying from one to six. It is in general a mellow vegetable mould, on a bottom of sand or gravel, which sometimes show themselves on the surface. Southwards it terminates in a point at Sutton-upon-Trent, the two clay divisions being in this place separated only by the river: northward, towards the borders of Lincolnshire, it at length degenerates into a bleak barren soil, moory, and full of swamps.

Underneath this diversified and generally productive soil, there occur in various places considerable beds of useful minerals. The coal-field of this county has many characteristics common to it with the coal-fields of Yorkshire, Northumberland, Derbyshire, and Durham. It begins at Teversall, and runs southward as far as Trowell and Wollaton. Between the brook Erewash and Derbyshire many pits have been sunk, the produce of which, transported by land or water carriage, is extensively consumed in distant as well as adjoining parts of the country. Eastward of this tract is found a large bed of limestone, which seems to overlap the coal, and is supposed to be a continuation of the great Durham bed, which terminates in the coast at Sunderland. It is copiously worked, both for mortar and manure. A kindred fossil, gypsum or alabaster, is found in great abundance. It is quarried and converted into plaster of Paris at Newark, Gotham, Beacon Hill, and several other places. Marl and building stone are also generally diffused: the latter article forms a considerable branch of trade at Maplebeck, and also at Mansfield, where the exportation of it has, since the year 1819, been much facilitated by a fine rail-way connecting the town with Pinxton on the Grand Junction Canal. The Mansfield stone, a species of marble, is of a close structure, and of a white cream-colour, durable, and fitted to receive a beautiful polish. Its hardness, however, renders the working of it so expensive, that more generally it is burnt and used as lime.

The plenty of these minerals, and the various traffic to which they give rise, communicate a new impulse to the agriculture of the county, already so highly favoured by the nature of the soil. The medium rental of Nottinghamshire, 659*l.* to the square mile, is not greatly above the average of England; but the country population live in a style of comfort and sufficiency which they too seldom enjoy elsewhere. The farms are generally small; the terms of the contract simple, and advantageous for the weaker party. About Worksop and Allarton, indeed, in one or two instances, the rent reaches to 1000*l.* at the rate of about 1*l.* per acre; but in other quarters it often sinks as far as 20*l.*; and on the whole it is more frequently below than above 100*l.* Leases have not yet become universal; but the humble agriculturist, though, strictly speaking, a tenant at will, usually inherits his farm through several generations, feels an interest something like that of property in it, and evinces the greateat readiness to profit by every species of improvement, which it lies within his power to adopt. The rural economy followed here presents little remarkable. The raising of grain, for domestic or external consumption, constitutes the chief employment of the husbandman; and grazing, though not by any means neglected, forms only a secondary object. Turnips and other green crops have long been introduced; wheat, barley, and oats are extensively cultivated,—the latter of so fine a quality, that judges of grain are able to distinguish the Nottingham oats from every other species. In Belvoir the usual rotation is one of three years: fallow, wheat or barley, beans or peas. In some of the wilder districts are to be seen considerable crops of *skegs*, a sort of oats peculiar to this county: it grows on the most barren lands, and the produce, double in quantity, is at least equal in weight to that of any other sort. It yields a sweet nutritious food for horses; and four quarters per acre (worth between two and three quarters of common oats,) can be raised from land where nothing else will come to maturity. Hops are another article of produce: they are cultivated in many farms of the north clay district, particularly about Retford, which is farther noted for the immense multitudes of its pigeons, supposed to be more numerous here than any where else in Britain. The hops of this county are nearly twice as strong as those of Kent; yet their flavour is by no means so agreeable; they are not favourites in the market, and the cultivation of them is not increasing. Weld, or woad, sometimes also called the dyers' weed, is reared in small quantities about Scrooby, and other places in the north. It has the advantage of growing on land already occupied by clover or barley; and in favourable seasons the produce of an acre will sometimes amount to half a ton, for which, however, the price fluctuates through all the intermediate degrees from 3*l*. to 12*l*.

The quantity of pasture, we have already observed, is much inferior to that of arable land. The Trent-bank district exhibits a mixture of both kinds; the fields near the river are almost entirely unploughed, as the frequent inundations of that stream would render the sowing of grain in its neighbourhood a precarious enterprise. The most extensive tract of grass land, however, is the space between Nottingham and Mansfield, which was once covered by the forest of Sherwood. This venerable tract, so famous in the legendary history of England, has now lost the greater part of its sylvan decorations; and Robin Hood, or any of his "merry men," would fail of procuring shelter or subsistence in it even for the shortest period. It once extended 25 miles between north and south, with a breadth of from seven to nine: but the continuous wood has now shrunk into isolated patches, and the red deer have totally vanished. The crown still retains the rights of *vert* and of *venison*, or of trees and game; of which the former has been for some centuries gradually declining, and the latter, as we have just observed, has within a few years become only a name. The property of the soil is supposed to be vested in the owners of several adjoining manors: but it may not be ploughed, and is at present of little value. The management of the forest is entrusted to the Justice in Eyre north of the Trent, and to several officers who are usually gentlemen of the neighbourhood. Under their superintendance, fresh plantations are rising; and it may be hoped that Sherwood will in time regain some portion of its faded honours. That the ground is well adapted for timber, is still evinced by the Parliament Oak in Clipstone Park, said to have been the rendezvous of a parliament in the time of Edward I.; by the Broad Oak, measuring twenty-seven feet and a half in circumference, which still flourishes in the same vicinity; and by the Langton Arbour (near Blidworth,) a large and ancient elm, which, some centuries ago, was sufficiently remarkable to give its name to one of the forest-walks, and to have a keeper specially appointed for it.

The manufactures of this county are varied and extensive. The fabrication of stockings has long been carried on at Nottingham on a great scale; to this are now added various preparations of silk, of thread, and British lace. Cotton mills have also been established in various places; they work for the hosiers of the neighbourhood, and likewise produce a supply of twist for the Manchester trade. Above thirty of those mills have been erected up and down the county. Another staple article of this district is malt, extensively manufactured at Nottingham, Newark, and Mansfield. It gives rise to a second branch of employment, that of brewing: the ales of Newark are reckoned little if at all inferior to those of Burton; they are circulated widely over the kingdom, and exported in considerable quantities. In addition to these general departments of industry, some others exist of a less prominent character, and more confined in their influence. Potteries of coarse red earthenware have been set up with tolerable success at Sutton in Ashfield. There is a manufactory of starch at Upton, near Southwell; a flourishing one of sailcloth at Retford; and dyeing and bleaching are carried on both at Nottingham and Newark.

The trade of Nottinghamshire consists in receiving and transmitting a variety of commodities prepared by the skill, or required by the wants, of several internal counties, to the commerce of which it serves as a thoroughfare, thus finding a lucrative employment for many thousands of its own population. The exports which pass either from or through the county are, lead, copper, coals, salt from Derbyshire and Cheshire; Staffordshire ware in considerable quantities; lime for agriculture or building; coarse earthenwares; pig iron, and cast metal goods; oak, timber and bark; stockings, sailcloth, and the various other articles of domestic manufacture. The imports for internal consumption, or for the supply of the neighbouring districts, are, timber, hemp, flax and iron, from the northern parts of Europe; groceries of all kinds; cotton wool; and large quantities of flints from Northfleet and other chalk pits near the Thames, for the use of the Staffordshire potteries.

The transport of these commodities is facilitated by an extensive and well organized system of inland navigation, the canals in this county being numerous, and the rivers excellently adapted for the purposes of commercial intercourse. No fewer than four of these canals take their rise in the Trent, and have a considerable part of their course within the limits of this county. The Nottingham canal extends about fifteen miles in a north-west direction to join that of Cromford, near Langley Bridge, not far from the termination of the Erewash cut; and is also connected by a side branch with the canal, which joins the rivers Trent and Mersey. Grantham Canal is also united with the Trent; as it terminates near Holme Pier Point, and sends a branch three miles upward to the town of Bingham. It falls no less than eighty-two feet within six miles, after entering this county, from Cromwell Bishop through the Wolds till it reaches the river. But the most important water-communication is the Chesterfield Canal, which commences in Derbyshire, close to the town from which it is named, crosses Sherwood forest, and, after a circuitous course of forty miles, passes into the Trent at Stockwith. At the same point likewise terminates another canal, that of the Idle river, which commences at Bawtry, and runs nearly east along the northern verge of the county, forming indeed more properly a river navigation than a cut. In one part of its course it has the name of Bycar Dyke; and about half a mile from Stockwith, its place of junction with the Trent, is Misterton Sas, a large sluice, contrived for the purpose of drawing off the floods from the lowlands through which that river flows.

Of the ancient history of Nottinghamshire very little is known. Originally it formed part of the settlements of the *Coritani;* in common with the rest of the island it became the prey of the Romans, and had several colonies of that enterprising people planted in it, as is evident, not only from written accounts, but also from various antiquities discovered at different times, and particularly from the roads, of which considerable vestiges still remain, leading to and from their different stations. Under the Saxon sway this district formed part of the kingdom of Mercia; and after the union of the heptarchy under one monarch, it continued to be governed by earls, bearing a similar title. After the conquest the same changes took place here as in other districts; the forest of Sherwood became noted as the resort of various outlaws, whose exploits have long formed the theme of many popular ballads; but the subsequent history of the county is too closely connected with that of the kingdom at large to admit of any particular exposition in this place.

At the close of the seventeenth century the number of houses in the county was 17,554; the inhabitants were estimated as amounting to 105,300. In 1801, there were found to be 68,558 males, and 71,792 females; in all 140,350 souls; of whom 35,513 were employed in trade and manufactures, and 23,904 in the various branches of agriculture. By the returns of 1811, the total number was found to have increased to 162,900; there being 79,057 males, and 83,843 females.

As to the poor, their condition, owing to the subdivision of farms, and other causes, is said to be preferable to that of such persons in most other counties of England, but of the rates and mode of management we possess no regular account, except for the county town. See *Beauties of England and Wales*, vol. xii.; and Lowe's *Agricultural Survey*.

NOVA SCOTIA is a peninsular province of British America, which stretches into the Atlantic from the province of New Brunswick. It lies between 43° 30′ and 48° 4′ of North Lat. and 58° 50′ and 67° of West Long. It is about 307 miles long, 154 broad, and has a superficial extent of nearly 14,000 square miles. It is bounded on the N. E. by the Gulf of St. Lawrence, on the E. the S. and S. W. by the Atlantic, and on the W. by the Bay of Florida and the province of New Brunswick, with which it is connected by an isthmus about eighteen miles wide. On the north-east coast, the general aspect of the country is bleak and barren, and the south-west coast, particularly in the county of Lunenburg, exhibits traces of industry and cultivation. The counties on the bay of Fundi are mountainous, and the hills which have not been cleared are covered with hard wood of various kinds. The summit of the remarkable land of Aspotageon is 500 feet above the level of the sea. Grain is raised in great abundance in the south-west counties upon a rich coarse loam. Iron, copper, limestone, gypsum, and freestone, are the principal mineral productions.

The principal rivers in Nova Scotia are, the *Annapolis* river, which, at high tides, is navigable for 14 miles by vessels of 100 tons; the *Shubenacaddie*, which flows into Chebequid Bay, after a course of 55 miles; and the Pigaquid, which runs 29 miles, and falls into the Bay of Minas. At high tides, vessels of 400 tons go up to Windsor, and those of 100 tons five miles higher.

The principal lakes are Rossignol, Porter's Lake, 15 miles long, and half a mile broad, Potowack Lake, and Shubenacaddie. Nova Scotia abounds in the finest bays, the largest of which is the Bay of Fundi, which stretches about 150 miles below New Brunswick and Nova Scotia. It is about 100 miles broad at its mouth, but at the Gut of Annapolis it contracts to 36 miles. It terminates in two branches, the western one of which is called Chignecto Channel, and the eastern the Basin of Minas. In the Bay of Fundi, the tides rise 30 feet, 40 in the Basin of Minas, and 60 in Chignecto Channel.

This province is divided into eight counties, which are divided into townships. The chief towns are HALIFAX, (already described under that article,) Pictou, containing about 500 inhabitants, chiefly Scotch; Liverpool, containing about 200 houses; Lunenburg, Barrington, Argyle, Yarmouth, Digley, ANNAPOLIS, (already described under that article,) and Windsor.

At Windsor, a college, called King's College, was established in 1789, and a charter was granted in 1802. The library is good. It has three scholarships of £30 per annum, for students in divinity. There is a small school in almost every town, and each mission has a schoolmaster, who receives a salary from the Society for the Propagation of the Gospel.

The population of Nova Scotia is about 88 000, the great body of which are of British origin. The established religion is that of the church of England.

In the year 1594, the coast of Nova Scotia was first visited by one May, an Englishman. In 1621, Sir W. Alexander obtained from James I. of Scotland a patent of Nova Scotia; and, in 1763, the province was finally ceded to Great Britain by the treaty of Paris. See Morses's *Geography*, p. 81.

NOVA ZEMBLA, or, in Russian, *Novaja Semlja*, or New Land, is a large island in the Arctic Seas, in the Russian government of Archangel, from which it is divided by Waygatz shoals. Its length is stated at 540 miles, and its breadth at 240; and, according to Hassel, it contains 125,264 square miles.

This island is uninhabited; but it is visited by fishermen and hunters, who are sent out by the merchants of Archangel and Mezen to obtain whales and walrusses, and to kill the Arctic bears and foxes for the sake of their furs. A narrow and crooked point, called Makoschin Schar, traverses the island from east to west. Pit-coal, asphaltum, and a salt lake, have been found in the interior. Nova Zembla extends from 69° to 76° of north latitude.

NOVEL ASSIGNMENT, in an action of trespass, is an assignment of time, place, &c. in a declaration, otherwise than it is in the writ. See ASSIGNMENT.

NOVOGOROD VELIKI, is an ancient city of Russia, and the see of an archbishop. It was once a large and flourishing town, but now consists of groups of wretched wooden houses, separated by ruins and empty fields. It is situated on a fine plain at the north end of the lake Ilmen, and upon the river Volchow, which divides it into two parts. The Torgaraia, or market town, stands on the right bank of the river; and on the left bank is the Sophiskaia, or quarter of St. Sophia. The latter is about 1½ miles in circuit, and is encircled with a rampart and ditch, flanked with old towers. The principal buildings are the Kremlin, or ancient palace of the czars; and the cathedral of St. Sophia, with brazen gates and numerous sculptures. There is here some trade in corn, and a few manufactures of couries and other articles. Population about 8000. East Long. 31° 19′ 39″, and North Lat. 58° 31′ 32″.

NUBIA, or Nouba, in the more extensive application of the name, comprehends all the countries, which are included between 11th and 24th degrees of north latitude; which are bounded by Egypt on the north, by the Arabian Gulf on the east, by Abyssinia on the south, and by Bornou on the west; an extent of territory about 700 miles in length, and 500 in breadth. The principal districts in this division of eastern Africa, are Senaar, Meroe, Dongola, and Nouba, or Nubia Proper. It is to the last of these that the following short account applies.

Nubia Proper, is the tract of country between Upper

Egypt and Dongola, lying along the banks of the Nile, between the 19th and 24th degrees of north latitude. It is divided into two parts, called Wady Kenous, and Wady el Nouba; the former extending from Assouan to Wady Seboua, and the latter from Seboua to Mosha, on the northern frontier of Dongola. In each of the subdivisions, a different language is spoken, but they are both inhabited by the same race of men.

The present Nubians derive their origin from the Bedouin Arabs who invaded the country, after the promulgation of the Mohammedan creed; and only a few descendants of the Christian inhabitants, who had adopted the tenets of their conquerors, are to be found in one or two places. Nubia was occupied for several centuries by two of these Arab tribes; but they were continually engaged in war with each other, and were at last rendered tributary to the kings of Dongola. The tribe of el Gharbye, the weaker of the two, procured from Sultan Selym the Great a body of Bosnian soldiers for their protection, who expelled the other tribe and their allies of Dongola; and whose descendants are still found in the vicinity of the castles of Assouan, Ibrim, and Say, excepted (according to the privilege of their progenitors) from all taxes and contributions. They call themselves the people of the castle; but by the Nubians are denominated Osmanli, or Turks; and are governed by their own agas, independent of the Nubian chiefs. The present governors of Nubia are three brothers, descendants of the chief whom Selym had placed over the country, at the head of the Bosnian troops. They bear the title of Kashef, which is given in Egypt to the governor of a district; and they pay an annual tribute of about 120*l.* to the Pasha of Egypt, as the Miry of Nubia; but not unfrequently a detachment of Turks from Egypt traverses the country, and levies a second assessment upon the oppressed inhabitants. The revenues of the governors arise from a tax upon every water-wheel employed in agriculture, generally at the rate of six sheep and six measures of grain for every wheel. There are about 700 of these wheels between the first and second cataracts, and in good years, the land watered by each wheel will yield about 1500 bushels of grain. The governors, also, take two clusters of fruit from every date tree, and levy a duty upon the dates which are exported. They derive a considerable income, likewise, from the administration of justice, which they literally sell to the best payer. It is estimated that each of them collects annually about 3000*l.*, of which he does not spend 300*l.* Each maintains a few hundred horsemen, consisting principally of their own relations, slaves, and armed negroes. With these they are constantly moving from place to place to collect the revenues; and, in the smaller villages, where the inhabitants are unable to resist, they commit the most oppressive acts of injustice. It is only, however, upon the property of the people that these governors exercise their tyranny; and they seldom inflict any punishment beyond a fine, except in cases of open rebellion. To extort money from their more wealthy subjects, these governors demand their daughters in marriage, for themselves or their sons, and then contrive to get possession of their property, as presents to the daughters.

The capital of Nubia, or the usual residence of the governors, is Dehr. (or Derr) a village of the larger class, containing about 200 mud houses, with a brick building of two stories for the governor. Its inhabitants are chiefly Turks, the descendants of the Bosnian soldiers already mentioned.

The climate of Nubia is extremely hot and dry. The thermometer of Fahrenheit has been observed at 124°. The plague is very rarely known in the country, and is never seen above the second cataract. There are few diseases of any kind, except the small-pox, which makes dreadful ravages, and which is shunned as a pestilence. Inoculation, though not unknown, is seldom practised, and the attempts to introduce vaccination have hitherto failed.

After the inundation of the Nile, the natives sow their grounds with a grain called Dhourra, upon which they chiefly depend for subsistence; and the dry stalks of which supply their cattle as provender during the summer. After the Dhourra harvest is ended, in December and January, the soil is irrigated by means of water-wheels turned by cows, and the fields are then sown for the second time with barley, wheat, beans, and tobacco. The wheat and barley are ripe in the middle of March; and, about the end of April, after they are reaped, the ground, when fertile, is sometimes sown a third time with Dhourra, and watered as before.

The principal trees and shrubs are the palm or date tree, the doum tree, a few vines, various thorny plants of the mimosa species, the tamarisk, the senna shrub, and the cotton tree.

The cattle of the Nubians consist of cows, sheep, and goats. Sometimes a few buffaloes are seen; and the wealthier inhabitants have asses. There are few camels, except among the merchants. There is a wild species of goat and also of sheep in the mountains; and the common grey gazelles are numerous in all parts of the country. Hares also are frequently seen, which the Arabs hunt with greyhounds. The principal birds are partridges of a small size, with red legs, large wild geese, storks, crows, a species of lapwing, a white water bird called kork, as large as a goose, the eagle, the bird called katta, and sparrows in immense flocks, which devour great part of the grain. The insects most commonly seen are beetles of various kinds; but generally a large black species among the sand.

The principal articles of commerce in Nubia, are cotton sent to Cairo, and dates, which are reckoned preferable to any in Egypt, particularly those of Derr and Ibrim. Young date trees are also exported to Egypt, as the trees propagated there from seed soon degenerate. In exchange for these articles, the Nubians receive dhourra, coarse linen, or Spanish dollars. The common currency of the country is the moud, or small measure of dhourra; and the dollar is rather an article of exchange than a current coin. Some other coins have been introduced since the Mamelouks took refuge in Nubia.

The houses of the Nubians are built of loose stones, or merely of mud; and are often so low that a person cannot stand upright, and in some cases have no roof at all. The furniture consists of about half a dozen coarse earthen jars for holding provisions; a few earthen plates, a hand-mill, a hatchet, burdocks for cooling water, sieves for cleaning the flour, a small coffee-pot, and some old mats to lie upon. This enumeration applies to the house of an Aga; and there are still fewer utensils in that of an ordinary person. Their chief article of food is dhourra bread, which is extremely coarse and insipid. The flour to be used through the day is ground by the women every morning, and made into very thin round cakes, which are usually eaten hot with sour milk. After becoming cold, they are less palatable, and are then broken down into a bowl, and boiled lentils poured over them, which is a frequent dish in the country. The natives rarely taste animal food, and even the governors are not accustomed to use it every day. Palm wine, sweet and thick, is commonly used in the larger villages; and an intoxicating liquor, called bouza, resembling beer, is made from dhourra or barley. A kind of spirit is also distilled from the date, and a kind of jelly or honey extracted from the same fruit.

The dress of the natives is usually a linen shirt only, or the woollen cloak of the Egyptian, with a small white linen cap, and sometimes a few rags twisted round it as a turban; but in the more southern parts the men are almost wholly uncovered. The women wrap themselves up in linen rags, or black woollen garments; they wear ear-rings and glass bracelets, which the poorer classes form of straw. The richer ladies put copper or silver rings on their ankles. Both sexes wear amulets of different kinds, chiefly mystical writings, in a leathern case. They all besmear their heads with fat, both by way of ornament, and as a protection against the heat of the sun. Boys and girls are entirely naked. The men are seldom unarmed, and the first article which every youth procures is a short crooked knife, which is tied under the left elbow beneath the shirt, and is drawn in every quarrel. Besides this, they carry upon any excursion a long heavy stick covered with iron at one extremity, or are armed with a lance about five feet long, with a target of a round or oblong shape, nearly four feet in length, made of the skin of the hippopotamus, and capable of resisting the blow of a lance or sabre. Those who can afford it, wear also a long strait sword, which they procure from Egypt. Some have match-locks, but fire arms are not common, and ammunition is remarkably scarce in the country.

The only Nubian manufactures are a coarse woollen and cotton cloth, made by the women on small looms; mats for bedding, formed of the palm leaves; and earthern bowls and plates, neatly made by the hand alone.

The Nubians are rather of lower stature than the Egyptians, but are muscular and well made, with fine animated features; but in some of the rocky districts, where food is scanty, they are thin meagre figures, almost like walking skeletons. They wear no mustachios, and the beard only under the chin. The women also are well formed; and, though not handsome, have generally sweet countenances and pleasing manners: but they are broken down by early and continual toil. They are more virtuous than any females in these eastern parts of Africa. No public women, so common in Egypt and other adjoining countries, are allowed in Nubia, except at Derr; and there they are not natives, but emancipated slaves, who betake themselves to this vile profession to gain a subsistence. The Nubians purchase their wives from the parents, generally at the price of 36 piastres. When they intermarry with the Ababde Arabs in their neighbourhood, they pay to the father of the bride six camels, and he returns three of them as the common property of the new married couple. In case of a divorce, half the value of these three goes back to the wife.

If one Nubian kill another, he must pay the debt of blood to the family of the deceased, and a fine to the governor of six camels, a cow, and seven sheep. Every wound inflicted by one person on another has its stated fine, according to the part of the body injured. Among the amusements of these people chess is common, and some other games. They play very melodious airs on an instrument resembling the Egyptian tamboura; and the girls are fond of singing.

The whole population of Nubia from Assouan to the frontiers of Dongola, a tract of country along the banks of the Nile, about 500 miles long, and half a mile at an average in breadth, is estimated only at 100,000.

The Nubians have no inclination for mercantile pursuits. They are strongly attached to their native soil; and, except those who travel to Egypt, seldom go beyond the precincts of their village. Considerable numbers go to Cairo, where they generally act as porters, and are preferred to the Egyptians on account of their honesty; but after a few years they return to their native spot with the little property which they have realized. They are a bolder and more independent race than the Egyptians; and in the skirmishes which frequently take place among neighbouring villages, even the women join in the battle, chiefly making use of slings. They are remarkable for a great degree of curiosity; but are generally hospitable towards strangers, and may be considered altogether as a people of honest and kindly dispositions. They are all Mohammedans in religion; but, excepting those who have been in Egypt, they are completely ignorant of its tenets.

There are numerous remains of Egyptian antiquities in Nubia, but the most distinguished is the large temple of Ebsambal, or Ypsambul, about a day and a half's journey below the second cataract; and which was first laid open by M. Belzoni, in August, 1817. This temple is cut out of the solid rock, and is in complete preservation. Its front is very magnificent, being 117 feet wide, and 86 feet high. The door is about 20 feet in height; and the pronaos, or first chamber, is 57 feet long, and 52 wide, having the roof supported by two rows of pillars, on each side of which is carved a figure about 30 feet high. The second hall is 22 feet high, 25 long, and 37 wide; the third is 37 feet wide; and the sanctuary is 23 feet by 12. There are in one of the recesses of the rock four sitting colossal figures, the largest in Egypt, except the great sphinx at the pyramids, to which they bear a proportion of two-thirds. They measure 25 feet across the shoulders, 15½ from the shoulders to the elbow, and 51 feet in height, exclusive of the caps, which are 14 feet. The face is 7 feet long, the beard 5½, and the ear 3½. See Murray's *History of Discoveries in Africa*; Legh's *Travels in Egypt*; Belzoni's *Researches in Egypt*; Burkhardt's *Travels in Nubia*. (*q*)

NUMBERS.*

NUMBERS, THEORY OF, a branch of analysis which has for its object, the exhibition and investigation of certain peculiar numerical properties; the relation of different orders of numbers with each other; the forms of numerical divisors; the solution of indeterminate equations, and the determination of their possibility, or impossibility, in rational numbers.

The theory of numbers, as a distinct branch of analysis, cannot claim an origin anterior to the commencement of the present century, although we may find traces of it in the works of some authors of great antiquity, as, for example, in the seventh, eighth, and ninth books of Euclid, where the subject is treated geometrically; the "Arenarius" of Archimedes, where it assumes its proper numerical character, and in which is contained the first hint of that important relation between an arithmetical and geometrical series, which constitutes the fundamental principle of our system of logarithms.

At this time, however, the imperfect notation employed by the Greeks interposed itself as an insuperable bar to the progress of this branch of science; and even after some ideas had been formed of the more general language of algebra, we still find Diophantus contending with the difficulties the numerical notation of his countrymen placed before him, and which prevented him from expressing, in an intelligible manner, various properties of numbers with which it is obvious he was by no means unacquainted.

From the time of this ancient writer, no step seems to have been made till about the beginning of the 17th century, when Bachet, a French analyst of considerable reputation, undertook the translation of the work of Diophantus into Latin, retaining also the Greek text. This translation was published in 1621, interspersed with numerous notes, where the first glance is caught of our present theory of numbers. These were afterwards considerably extended by Fermat, in his edition of the same work, published after his death in 1670, where we find many of the most elegant theorems in this branch of analysis; but they are generally left without demonstration. This omission he accounts for in one of his notes, by stating, that he was himself preparing a treatise on the theory of numbers, which would contain many new and interesting numerical propositions; but, unfortunately, this work never appeared, and most of his propositions remained without demonstrations for a considerable time, although at present one only has resisted the talents and perseverance of modern mathematicians; this one may be briefly enunciated as follows. "The formula $x^n \pm y^n = z^n$ is impossible, in rational numbers, for every value of n greater than 2." The demonstration of this theorem was proposed a few years back as the prize subject of the mathematical class by the National Institute of France, but received no satisfactory solution.

During the latter part of the last century, and the beginning of the present, the theory of numbers engaged the attention of many very celebrated algebraists, amongst whom are found Euler, Waring, and Lagrange. The former, besides what is contained in the second volume of his "Algebra," and his "Analysis Infinitorum," has various papers on the subject in the Transactions of the Academy of Petersburgh. What has been done by Waring will be found in the fifth chapter of his "Meditationes Algebraicæ;" and Lagrange, who, more than any other writer, has extended this branch by the invention of many new propositions, has several interesting papers on the subject in the Memoirs of Berlin, besides what are contained in his edition of the French Translation of Euler's Algebra. It is, however, only during the present century that the theory of numbers has been reduced to a regular system—a task which was first performed by Legendre, in his "Essai sur la Theorié des Nombres;" and, nearly at the same time, Gauss published his "Disquisitiones Arithmeticæ," in which latter work a new and highly interesting application of this doctrine is made to the solution of binomial equations of the form $x^n - 1 = 0$, on which depends the division of the circle into a given number of parts, as was before known by the Cotesian theorem. To these works we may also add an English treatise on the same subject, by Mr. Barlow, of the Royal Military Academy, which contains several new theorems, and a simplification of some of those already alluded to in the above historical sketch.

Properties of Numbers.

(1.) In order to reduce the doctrine of numbers to a regular system or theory, they are divided into distinct classes, as *even* and *odd* numbers, *prime* numbers, *polygonal* and *figurate* numbers, &c. &c. which we shall treat of separately, according to their natural order.

Even and Odd Numbers.

(2.) The most simple distinction of numbers is that of *even* and *odd*, the former class being all such as are divisible by 2 without leaving a remainder, and the latter those which cannot be exactly divided by 2, or which cannot be separated into two equal integral parts.

For the sake of conciseness of expression, the former are said to be of the form $2n$, and the latter of the form $2n + 1$; and, to avoid the repetition of these words, the same is otherwise expressed by the symbol $\fallingdotseq$; whence $a \fallingdotseq 2n$, or $a \fallingdotseq 2n + 1$, is to read, a of the form $2n$, or a of the form $2n + 1$.

In the same way, the expressions

$$a \fallingdotseq 4n \pm 1$$
$$a \fallingdotseq 6n \pm 1, \text{ \&c.}$$

signify, that the number denoted by a, when divided by 4, will leave a remainder $+ 1$, or $- 1$, or, which is the same, 1 or 3; and, in the second case, that the number denoted by a, when divided by 6, will leave a remainder 1 or 5.

The properties of numbers, as divided simply into even and odd, are very few, and these few of the most obvious nature; such, for example, as the following.

1. The sum or difference of two even numbers is an even number; for if $a \fallingdotseq 2n$ and $a' \fallingdotseq 2n'$, then $a \pm a' \fallingdotseq 2n \pm 2n' \fallingdotseq 2n''$.

2. In the same way, we may show that the sum or difference of two odd numbers is an even number;

For, let $a \fallingdotseq 2n + 1$

$$\underline{a' \fallingdotseq 2n' + 1}$$

Then $a \pm a' \fallingdotseq (2n + 1) \pm (2n' + 1) \fallingdotseq 2n''$.

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* The Editor has been indebted for this article to Mr. P. BARLOW, of the Royal Military Academy, Woolwich

3. The product of two even, or of an even and odd number, is an even number, but the product of two odd numbers is an odd number; that is,

$$2\,n \times 2\,n' \fallingdotseq 2\,n''$$
$$2\,n \times (2\,n' + 1) \fallingdotseq 2\,n''$$
$$(2\,n' + 1)\,(2\,n' + 1) \fallingdotseq 2\,n'' + 1,$$ as is obvious.

4. If an odd number divide an even number, it will divide the half of it. For, by the last proposition, the quotient must be an even number; that is, we must have $\frac{2\,n}{2\,n' + 1} = 2\,n''$

Consequently $\frac{n}{2\,n' + 1} = n''$.

Of Numbers prime to each other.

(3.) Two numbers are said to be prime to each other, when they have not a common divisor; and those numbers which have no divisor are called prime numbers.

1. If a and b be two numbers prime to each other, then will their sum or difference be prime to each of them.

For if $(a + b)$ and a had a common divisor p, then $(a + b) - a$ would have the same common divisor; that is, b and a would have a common divisor, which is contrary to the supposition; and the same may be shown for the difference $a - b$.

2. In a similar manner it may be demonstrated, that if two numbers are prime to each other, their sum and difference are prime to each other, or will only have 2 for a common divisor.

3. If a and p be two numbers prime to each other, there cannot be another number b prime to p, that renders the product $a\,b$ divisible by p.

4. Hence, neither the sum nor the difference of two fractions, which are in their lowest terms, and of which the denominator of the one contains a factor not common to the other, can be equal to an integral number.

Of the Factors and Divisors of Composite Numbers.

(4.) The factors of composite numbers are, those numbers the continued product of which produces the composite number. Thus, 3, 5, 7 are the factors of the composite number 105; and the divisors are those numbers which divide the given number, without leaving a remainder.

1. Every composite number may be represented by the formula $p = a^n\, b^m\, c^q$, &c. in which a, b, c, &c. are its prime factors.

For, let p be first divided by the highest power of a contained in it, as a^n; and the quotient by the highest power of b contained in it, as b^m; and this quotient again by the highest power c contained in it, as c^q; and so on, as long as division can be made; and we shall thus have

$$p = a^n\, b^m\, c^q, \text{ \&c.}$$

2. Hence the number of divisors of any number p, will be found equal to the product

$$(n + 1)\,(m + 1)\,(q + 1) \text{ \&c.}$$

For it is obvious that p will be divisible by a, and every power of a to a^m, or by the terms

$$a,\ a^2,\ a^3, \text{ \&c. } a^n.$$

Also by b, and every power of b, to b^m; that is, by each of the terms

$$b,\ b^2,\ b^3, \text{ \&c. } b^m.$$

And, in the same manner, it will be divisible by c, and every power of c, to c^q, and so on; as also by every possible combination of the terms in the above series. But every possible combination can only be obtained by the product

$$(a + a^2 + a^3, \text{ \&c. } a^n) \times (b + b^2 + b^3, \text{ \&c. } b^m) \times (c + c^2 + c^3 + \text{ \&c. } c^z);$$

and the number of terms of this product is obviously equal to

$$(n + 1)\,(m + 1)\,(q + 1) \text{ \&c.}$$

which therefore expresses the number of divisors of the number p.

Example 1. Required the number of divisors of the number 360.

Here $360 = 2^3.\,3^2.\,5^1$; consequently the number of its divisors will be $(3 + 1)\,(2 + 1)\,(1 + 1) = 4.3.2. = 24$.

Example. It is required to find how many numbers there are which will divide 1000, without leaving a remainder.

First, $1000 = 2^3\ 5^3$; whence

$$(3 + 1)\,(3 + 1) = 4.4 = 16,$$

the number of the divisors sought.

Example 3. To find the least number that shall have a given number of divisors; as for instance, 30.

First, $30 = 2.3.5.$; therefore the number must have the form

$$p = a^1.\, b^2.\, c^4;$$

And it will be the least when that number which has the greatest index is the least, and so on in order; therefore, in the case in question, if we take $c = 2$, $b = 3$, and $a = 5$, we shall have

$$5 \times 3^2 \times 2^4 = 720$$

for the least number having 30 divisors.

It will be observed, that, in all these cases, the number itself is considered as one of the divisors.

3. If $p = a^n\, b^m\, c^q$, &c. be taken to represent any integral number, the sum of all its divisors will be expressed by the formula

$$\frac{a^{n+1}-1}{a-1} \times \frac{b^{m+1}-1}{b-1} \times \frac{c^{q+1}-1}{c-1}, \text{ \&c.}$$

For we have seen that every divisor of p is contained in the product

$$(a+a^2+a^3, \text{ \&c. } a^n)\,(b+b^2+b^3, \text{ \&c. } b^m)\,(c+c^2+c^3, \text{ \&c. } c^q)$$

and, by the common rule for summing a geometrical progression,

$$a + a^2 + a^3 - a^n = \frac{a^{n+1}-1}{a-1}$$
$$b + b^2 + b^3 - b^m = \frac{b^{m+1}-1}{b-1}, \text{ \&c.}$$

Consequently the above product may also be expressed by $\frac{a^{n+1}-1}{a-1} \times \frac{b^{m+1}-1}{b-1} \times \frac{c^{q+1}-1}{c-1}$, &c. and which is obviously equal to the sum of all the divisors of p.

Example 1. Required the sum of all the divisors of the number 360.

First, $360 = 2^3.3^2.5^1$, whence

$$\frac{2^4-1}{2-1} \times \frac{3-1}{3-1} \times \frac{5^2-1}{5-1} = 15.13.6 = 1170,$$

the sum of all the divisors sought.

4. If $p = a^n\, b^m\, c^q$ &c. represent any number, a, b, c, &c. being its prime factors; then will

$$p \times \frac{a-1}{a} \times \frac{b-1}{b} \times \frac{c-1}{c}$$

express the number of integers, which are less than p, and also prime to it.

Example 1. Find how many numbers there are which are less than 100, being also prime to it.

First, $100 = 2^2\ 5^2$; therefore

$$100 \times \frac{2-1}{2} \times \frac{5-1}{5} = 40$$

the number sought; these being as follow, *viz.*

1 13 27 39 51 63 77 89
3 17 29 41 53 67 79 91
7 19 31 43 57 69 81 93
9 21 33 47 59 71 83 97
11 23 37 49 61 73 87 99

Example 2. How many numbers are there which are less than 360, and also prime to it?

Here $360 = 2^3\ 3^2\ 5^1$, wherefore

$$360 \times \frac{2-1}{2} \times \frac{3-1}{3} \times \frac{5-1}{5} = 96, \text{the number sought.}$$

Of Perfect Numbers.

(5.) A perfect number is that which is equal to the sum of all its divisors.

If $2^n - 1$ is taken equal to a prime number, that is, if the index n be so taken as to fulfil this condition, then $2^{n-1} \times (2^n - 1) = N$, will be a perfect number.

For, by the preceding proportion, the sum of the divisors of the formula $2^{n-1}(2^n - 1)$ will be represented by

$$\frac{2^n - 1}{2-1} \times \frac{(2^n-1)^2 - 1}{(2^n - 1)\ - 1}.$$

But in this expression, unity is included as a divisor, and consequently N also; but this last, by the definition of perfect numbers, is to be excluded; and, therefore, in this case, the expression becomes,

$$\frac{2^n-1}{2-1} \times \frac{(2^n-1)^2-1}{(2^n-1)\ -1} - 2^{n-1}(2^n-1) =$$
$$(2^n-1)(2^n-1+1) - 2^{n-1}(2^n-1) =$$
$$2(2^n-1\ .\ (2^{n-1} - 2^{n-1}(2^n-1) = 2^{n-1}(2^n-1) = N.$$

That is the sum of all the aliquot parts of $N = N$; therefore N is a perfect number.

If $n=2$ then $2\ \ (2^2\ -1)=6$
$n=3 \qquad 2^2\ (2^3\ -1)=28$
$n=5 \qquad 2^4\ (2^5\ -1)=496$
$n=7 \qquad 2^6\ (2^7\ -1)=8128$
$n=13 \qquad 2^{12}(2^{13}-1)=33550336$
$n=17 \qquad 2^{16}(2^{17}-1)=8589869056$
$n=19 \qquad 2^{18}(2^{19}-1)=137438691328$
$n=31 \qquad 2^{30}(2^{31}-1)=2305843008139952128$

which are all perfect numbers.

Of Amicable Numbers.

(6.) Amicable numbers are those pairs of numbers, of which each is equal to the sum of all the divisors of the others.

1. To find a pair of amicable numbers M and N. Make $M = a^m\ b^n\ c^p$, &c., and $N = \alpha^n\ \beta^v\ \gamma^\pi$, &c.; then, from the above definition, and from what has been already delivered with respect to divisors, it follows that we must have

$$\frac{a^{m+1}-1}{a-1} \times \frac{b^{n+1}-1}{b-1} \times \frac{c^{p+1}-1}{c-1} = N + M, \text{ and}$$
$$\frac{\alpha^{n+1}-1}{\alpha-1} \times \frac{\beta^{v+1}-1}{\beta-1} \times \frac{\gamma^{\pi+1}-1}{\gamma-1} = N + M.$$

Hence it also appears, that in order that the numbers N and M may be amicable, these formulæ must be equal to each other, and each equal to N + M. Now this condition is fulfilled by finding such a power of 2, as 2^n, that $3.2^n - 1$, $6.2^n - 1$, and $18.2^{2n} - 1$, may be all prime numbers. Or, making $2n = w$, we must have $3\,w - 1 = b$, $6\,w - 1 = c$, $18\,w^n - 1 = d$, all prime numbers, then will

$$N = 2^{n+1}\,d \text{ and } M = 2_{n+1}\,b\,c$$

be the pair of amicable numbers sought.

By making $n = 1$, or $2^n = w = 2$, we have
$3\,w - 1 = b = 5$; $b\,w - 1 = c = 11$, $18\,w^2 - 1 = d = 71$,
and consequently

$$2^{n+1}\,d = 4 \times 71 = 284 = N$$
$$2^{n+1}\,b\,c = 4 \times 5 \times 11 = 220 = M,$$

which are the least pair of amicable numbers. The next two pairs are

17296 and 18416
9363583 and 9437056

Of Figurate Numbers.

(7.) Figurate numbers are all those which fall under the general expression,

$$\frac{n\,(n+1)\,(n+2)\,(2+3)\ \&c.\ n+m)}{1\ .\ 2\ .\ 3\ .\ 4\ \&c.\ m}$$

and they are said to be of the 1st, 2d, 3d, &c. order, accordingly as $m = 1, 2, 3$, &c. thus,

		General terms.
Natural series,	1, 2, 3, 4, 5, 6, &c.	n
1st order,	1, 3, 6, 10, 15, 21, &c.	$\frac{n\,(n+1)}{1\,.\,2}$
2d order,	1, 4, 10, 20, 35, 56, &c.	$\frac{n\,(n+1)\,(n+2)}{1\,.\,2\,.\,3}$
3d order,	1, 5, 15, 35, 70, 126, &c.	$\frac{n\,(n+1)\ldots(n+3)}{1.\,2.\,.\,.\,.\,4}$

1. One of the principal properties of these numbers is as follows. If the nth term of any order of figurate numbers be added to the next term of the next inferior order, the sum will be the next term of the same order as the former.

2. Another property is, that if the nth term of the natural series be multiplied by the $n + 1$ term of any order m, the product will be equal to $m + 2$ times, the nth term of the order $m + 1$.

Thus, taking the fifth and sixth terms of the foregoing series, we have,

$$5 \times 6 = 2 \times 15;\ 5 \times 21 = 3 \times 35;\ 5 \times 56 = 4 \times 70.$$

That this property is general may be shown immediately from our definition; for

$$n\,(n+1) = 2\,\frac{n\,(n+1)}{1\,.\,2}$$
$$n\,\frac{(n+1)\,(n+2)}{1\ .\ 2} = 3 \times \frac{n\,(n+1)\,(n+2)}{1\,.\,2\,.\,3}$$
$$\&c. \qquad\qquad \&c.$$

It is remarkable that Fermat, in his enunciation of this theorem, speaks of it not only as a very simple and elegant proposition, but as one also whose demonstration would occupy more space and time than he could afford to bestow upon it. He says, "Nec existimo pulchrius aut generalius in numeris posse dari theorema, cujus demonstrationem margini inserere nec vacat nec licet." (*Notes on Diophantus*, p. 16.)

Of Polygonal Numbers.

(8.) Polygonal numbers are the sums of different and independent arithmetical series, and are termed lineal, triangular, square, pentagonal, &c. numbers, according to the nature of the series from which they are generated.

Lineal numbers are formed from a series of units; thus,

Units 1, 1, 1, 1, 1, &c.
Lineal Numbers 1, 2, 3, 4, 5, &c.

Triangular numbers are the successive sums of the terms of an arithmetical series beginning with unity, the common difference of the terms being 1; thus,

Arith. series, 1, 2, 3, 4, 5, &c.
Trian. num. 1, 3, 6, 10, 15, &c.

Quadrangular, or square numbers, are formed from an arithmetical series, the difference of whose terms is, 2: thus,

Arith. series, 1, 3, 5, 7, 9, &c.
Quad. num. 1, 4, 9, 16, 25, &c.

Pentagonal numbers are those formed from an arithmetical series whose difference are 3, thus,

Arith. ser. 1, 4, 7, 10, 13, &c.
Pen. num. 1, 5, 12, 22, 35, &c.

and universally the m-gonal series of numbers is formed from the successive sums of an arithmetical series, beginning with unity, and whose common difference is *m*.

1. Every polygonal number of the denomination *m*, or every m-gonal number, is expressed by the formula

$$\frac{(m-2)\,n^2-(m-4)\,n}{2}$$

Hence the natural numbers are of the form *n*.

triangular numbers is $\frac{n(+1)}{1.2}$
quadrangular numbers is $\frac{2n^2-on}{2}$
pentagonal numbers is $\frac{4n^2-2n}{2}$
&c. &c. &c.

The most remarkable property of polygonal numbers may be enumerated as follows:

1. Every number whatever, is either a triangular number, or the sum of two or three triangular numbers; a square, or the sum of two, three, or four squares; a pentagonal, or the sum of two, three, four, or five pentagonal numbers; and so on, for hexagonal, heptagonals, &c. Or, the same may be more generally expressed, thus:

If *m* represent the denomination of any order of polygonals, then is every number N, the sum of *m* polygonals of that order; it being understood that any of those polygonals may become zero. This is one of the propositions of Fermat, but left by him without demonstration. The second proposition, viz. that every number is a square, or the sum of two, three, or four squares, was first demonstrated by Lagrange; and afterwards, the first part relating to triangular numbers was given by Legendre, in his "Essai sur la theorie des Nombres:" and lately, the entire proposition has been demonstrated by M. Cauchy, in the *Memoirs of the Institute of France*, for 1814. This demonstration, however, occupies too much space to attempt the exhibition of it in this place. We may, however, observe, that M. Cauchy has, in some measure, restricted the difficulties of the demonstration, by first showing that of the *m* polygonals, whose sum makes up any given number *m*—4 of those polygonals, may be equal to unity.

Of Prime Numbers.

9. Prime numbers are those which cannot be divided into any equal integral parts, greater than unity, or they are numbers which cannot be produced by the multiplication of any integral factors.

The problem of finding prime numbers was agitated as far back as the time of Eratosthenes, who invented what he called his *κοσκινον*, or *sieve*, for excluding those numbers that are not primes, and, consequently, thus discovering those that are. The principle of this method, which is the same as that employed by modern writers for ascertaining those numbers, is as follows:

Having written down, in their proper order, all odd numbers, from 1 to any extent required; as, for example, 100, thus,

$$\begin{array}{cccccccccc}
1 & 3 & 5 & 7 & \dot{9} & 11 & 13 & \ddot{15} & 17 & 19 \\
\ddot{21} & 23 & \dot{25} & \ddot{27} & 29 & 31 & \dot{33} & \ddot{35} & 37 & \dot{39} \\
41 & 43 & \ddot{45} & 47 & \dot{49} & \dot{51} & 53 & \dot{55} & \dot{57} & 59 \\
61 & \ddot{63} & \dot{65} & 67 & \dot{69} & 71 & \dot{73} & \ddot{75} & \dot{77} & 79 \\
\dot{81} & 83 & \dot{85} & \dot{87} & 89 & \dot{91} & \dot{93} & \dot{95} & 97 & 99
\end{array}$$

We begin at 3, and over every third number from that place, we put a point: all those numbers being divisible by 3. Then from 5, a point is placed over every 5th number, these being divisible by 5. Then from 7, and over every 7th number, a point is also placed, these being all divisible by 7; then all the other numbers not pointed, will be primes; because 7 is the greatest prime number less than $\sqrt{100}$; and if a number cannot be divided by some number less than the square root of itself, it is a prime number.

In this way the prime numbers have been obtained to a very considerable extent; the most extensive table, however, is that of Mr. Burckhardt, which gives the least factor of all numbers from 1 to 3,000,000, and consequently exhibits all the prime numbers within the same limits. But no general rule has yet been given for ascertaining, in a direct manner, whether a given number is or is not a prime. Prime numbers possess several remarkable properties, some few of which we may enumerate, but we cannot attempt the demonstrations, as these would occupy more room than we can bestow upon the subject in this place.

1. Every prime number, greater than 2, is of the form $4n \pm 1$.

That is, if divided by 4, it will leave a remainder 1 or 3. But the converse of the proportion is not true; viz. that every number of the above form is a prime.

2. Every prime number greater than 3, is of the form $6n \pm 1$.

3. No algebraical formula can be found that will contain prime numbers only.

Notwithstanding the generality of this proposition, certain formulæ have been found, which are remarkable for containing a great many prime numbers; such are x^2+x41, x^2+x+17, and $2x^2+29$. In the first of which, by giving to x all successive values in the series 0, 1, 2, 3, &c. the first forty terms will be prime numbers; the second, in like manner, has its first seventeen terms primes, and the latter twenty-nine.

Fermat asserted, that the formula 2^m+1, would always be a prime, while *m* was taken any term in the series 1, 2. 4, 8, 16, &c.; but Euler found that

$2^{32}+1=641\times6700417$ was not a prime.

4. The number of prime numbers is infinite; and if N be made to represent any number, then will the expression $\frac{N}{h \log. N - 1.08366}$ denotes the number of prime numbers that are less than N, *very nearly.*

5. The sum of any number of prime numbers in arithmetical progression is a composite number.

6. If a be a prime number, then will the expression

$$1 \;.\; 2 \;.\; 3 \;.\; 4 \;.\; 5, \&c.\; (a-1)+1$$

be divisible by a.

We have said, that no rule has yet been invented for ascertaining whether or not a given number be a prime; but we ought in fact to have made an exception of the above formula, which is true for prime numbers, and for prime numbers only, and therefore, theoretically, it supplies such a rule as that alluded to; but unfortunately it is only theoretical, for the magnitude of the product is such, even for a small prime number, that is impossible to make it answer any practical purpose.

This theorem was invented by Sir John Wilson, and is published by his friend Waring in his *Meditationes Algebraicæ*, p. 380, but without demonstration. This, however, was afterwards supplied by Lagrange, in the *New Memoirs of Berlin* for 1771.

7. If m be a prime number, and x any number not divisible by m, then will the formula $x^{m-1}-1$ be divisible by m.

Of square Numbers, and their possible and impossible forms.

10. In the indeterminate and diophantine analysis, we are frequently required to find such values of the indeterminate letter, or letters, as will make some proposed formula a square, and not unfrequently the problem may be in itself impossible. It is, therefore, necessary for us to have some means of determining *a priori* whether the problem proposed be possible or impossible, which is a question falling within the range of the theory of numbers. For example, every square number is of the form $4n$ or $4n+1$; therefore, if we were required to find such integral value of n, that $4n-1$ should be a square, we should know the solution to be impossible, and save ourselves the labour of research.

1. All square numbers are of the same form with relation to any given modulus a, as the series of squares

$$0^2,\ 1^2,\ 2^2,\ 3^2,\ \&c\ \left(\tfrac{1}{2}a\right)^2,$$

when a is an even number; and as the squares

$$0^2,\ 1^2,\ 2^2,\ 3^2,\ \&c. \left(\frac{a-1}{2}\right)^2$$

when a is odd.

From this general proposition we may immediately deduce the possible and impossible forms of square numbers to any extent; but it will be sufficient for our purpose to give them as far as the modulus 10 only.

The modulus is that number by which the form is determined.

Moduli.	Formulæ.
2	$2n$, $2n+1$
3	$3n$, $3n+1$
4	$4n$, $4n+1$
5	$5n$, $5n \pm 1$
6	$6n$, $6n+1$, $6n+3$, $6n+4$
7	$7n$, $7n+1$, $7n+2$, $7n+4$
8	$8n$, $8n+1$, $8n+4$
9	$9n$, $9n+1$, $9n+4$, $9n+7$
10	$10n$, $10n \pm 1$, $10n \pm 4$, $10n \pm 5$

Since all square numbers must be of one or other of the above forms, all other formulæ to the same *moduli* must be impossible; and hence, by exclusion, we have,

Moduli.	Impossible Formulæ.
2	
3	$3n+2$
4	$4n+2$, $4n+3$
5	$5n+2$, $5n+3$
6	$6n+2$, $6n+5$
7	$7n+2$, $7n+5$, $7n+6$
8	$8n \pm 2$, $8n \pm 3$, $8n+7$
9	$9n+2$, $9n \pm 3$, $9n+5$, $9n+8$
10	$10n \pm 2$, $10n \pm 3$.

No numbers falling under these forms can be a square number.

Since, by the first table, every square number divided by 10 will leave a remainder ±1, ±4, or ±5, it follows that every square number must terminate with one of the digits, 0, 1, 4, 5, 6, or 9; and no number, whose last digit is 3, 7, or 8, can be a square number. If we were to make a similar examination of the impossible forms to modulus 100, we should find,

1. That a square number cannot be terminated with an odd number of ciphers.

2. If the last figure of a square be at 4, the last but one will be an even number.

3. If a square number terminate with a 5, it will terminate with 25.

4. If a square terminates with an odd digit, the last figure but one will be even; and if it terminates in any even digit except 4, the last figure but one will be odd.

5. No square number can terminate with two equal digits, except two ciphers, or two 4's.

6. A square number cannot terminate with more than three equal digits, unless they are ciphers; nor can it terminate with three, unless they are 4's.

The celebrated calculating boy, Zera Colburn, had intuitively acquired a knowledge of these and various other excluding theorems

By means of the above table, which may be called the lineal impossible forms of square numbers, we readily demonstrate various impossible quadratic forms, such as

$$\begin{array}{ll} 2t^2 \pm 3n^2 = w^2 & 2t^2 \pm 6n^2 = w^2 \\ 5t^2 \pm 3n^2 = w^2 & 5t^2 \pm 6n^2 = w^2 \\ 2t^2 \pm 5n^2 = w^2 & 2t^2 \pm 10n^2 = w^2 \\ 3t^2 \pm 5n^2 = w^2 & 3t^2 \pm 10n^2 = w^2 \end{array}$$

which are all impossible equations in integral numbers; and we might have extended the series to any length at pleasure: we prefer, however, giving the following proposition for ascertaining the possibility or impossibility of any proposed indeterminate quadratic form or equation, $ax^2+by^2=cz^2$. This is effected as follows: Find the form of all squares to modulus a, and if b and c are both found in the series of remainders, or if neither of them be found there, the equation may be possible; but if one of them be found there, and the other not, the equation is certainly impossible.

But if one of the two first conditions have place, then find the forms of all square numbers to modulus b, which must be submitted to the same test with regard to a and c.

If here, both numbers, or neither be found in the series of remainders, the equation may still be possible; but otherwise it will be impossible.

Supposing the former to be the case, proceed in the same way with c as a modulus; and if a and $(c-b)$ are both or neither of them found in the series of remainders, the equation is possible, but otherwise it is certainly impossible, and it would, therefore, in this case be useless to persevere in the solution.

Of Cubes and higher Powers.

(11.) All cubes are of the same form in reference to any modulus a, as the series of cubes

$$0^3,\ 1^3,\ 2^3,\ 3^3,\ \text{\&c.}\ (a-1)^3$$

From which general proposition we might deduce, as in the preceding article, tables of the possible and impossible forms of cube numbers, both lineal and quadratic; we shall, however, restrict ourselves to the following only, viz.

1. All cube numbers referred to modulus 6, have the same forms as their roots; thus

$$\left.\begin{array}{l}(6n+0)^3\\(6n+1)^3\\(6n+2)^3\\(6n+3)^3\\(6n+4)^4\\(6n+5)^5\end{array}\right\}\text{are of the same form as}\left\{\begin{array}{l}0^3 \rightleftarrows 6\,n+0\\1^3 \rightleftarrows 6\,n+1\\2^3 \rightleftarrows 6\,n+2\\3^3 \rightleftarrows 6\,n+3\\4^3 \rightleftarrows 6\,n+4\\5^3 \rightleftarrows 6\,n+5\end{array}\right.$$

Hence the difference between any integral cube and its root is divisible by 6.

2. The sum or difference of two integral cubes cannot be a cube; or the equation

$$x^3 \pm y^3 = z^3$$

is impossible in integers; and being impossible in integers, it is also impossible in fractions.

3. The sum or difference of two biquadratics cannot be a square, and therefore, *a fortiori*, it cannot be a biquadratic; that is, the equation,

$$x^4 \pm y^4 = z^4$$

is impossible either in integers or fractions.

4. And generally, n being any number greater than 2, the equation

$$x^n \pm y^n = z^n$$

is impossible.

It is to be observed, however, that this latter general proposition has never yet received a satisfactory demonstration. The only actual advances made towards it has been to show, that, if the equation were possible, the roots must have some one of the following forms, viz.

$$\left.\begin{array}{l}x-y \rightleftarrows r^n\\x-z \rightleftarrows s^n\\y+z \rightleftarrows t^n\end{array}\right\}\text{ or }\left\{\begin{array}{l}x-y \rightleftarrows n^{n-1}\,r^n\\x-z \rightleftarrows s^n\\y+z \rightleftarrows t^n\end{array}\right.$$

$$\left.\begin{array}{l}x-y \rightleftarrows r^n\\x-z \rightleftarrows n^{n-1}\,s^n\\y+z \rightleftarrows t^n\end{array}\right\}\text{ or }\left\{\begin{array}{l}x-y \rightleftarrows r^n\\x-z \rightleftarrows s^n\\y+z \rightleftarrows n^{n-1}\,t^n\end{array}\right.$$

which, however, does not amount to a demonstration of the impossibility of the equation.

5. The following is a table showing the possible forms of all powers from the second to the twelfth.

$$\begin{array}{llll}
x^2 & \rightleftarrows 3\,n \text{ or } 3\,n+1, & \rightleftarrows 5\,n \text{ or } 5\,n \pm 1\\
x^3 & \rightleftarrows & \rightleftarrows 7\,n \text{ or } 7\,n \pm 1\\
x^4 & \rightleftarrows 5\,n \text{ or } 5\,n+1, & \rightleftarrows\\
x^5 & \rightleftarrows & \rightleftarrows 11\,n \text{ or } 11\,n \pm 1\\
x^6 & \rightleftarrows 7\,n \text{ or } 7\,n+1. & \rightleftarrows 13\,n \text{ or } 13\,n \pm 1\\
x^7 & \rightleftarrows & \rightleftarrows\\
x^8 & \rightleftarrows & \rightleftarrows 17\,n \text{ or } 17\,n \pm 1\\
x^9 & \rightleftarrows & \rightleftarrows 19\,n \text{ or } 19\,n \pm 1\\
x^{10} & \rightleftarrows 11\,n \text{ or } 11\,n+1 & \rightleftarrows\\
x^{11} & \rightleftarrows & \rightleftarrows 23\,n \text{ or } 23\,n \pm 1\\
x^{12} & \rightleftarrows 13\,n \text{ or } 13\,n+1 & \rightleftarrows
\end{array}$$

Since neither $7+1$, nor $2 \times 7 + 1$, is a prime number, the 7th powers are not reducible to any form similar to the above.

6. To these properties of powers in general we may add, that the difference of any two equal powers is divisible by the difference of their roots; and also by the sum of the roots, if the powers be even.

7. The sum of any two equal odd powers is always divisible by the sum of the roots.

8 The nth difference of any consecutive nth powers is constant, and equal to the product

$$1.\ 2.\ 3.\ 4.\ \text{\&c.}\ n.$$

Form and Properties of Products.

(12.) The most remarkable properties of products are contained in the following theorems.

1. The product of the sum and difference of two numbers, is equal to the difference of their squares; that is, $(x+y)\ (x-y) = x^2 - y^2$.

2. The product of the sum of two squares, by the sum of two squares, is also the sum of two squares;

Or $(x^2+y^2)\ (x'^2+y'^2) \rightleftarrows x''^2+y''^2$.

For

$$(x^2+y^2)(x'^2+y'^2) = \begin{cases}(x\,x'+y\,y')^2+(x\,y'-x'y)^2 \text{ or,}\\(x\,x'-y\,y')^2+(x\,y'+x'y)^2\end{cases}$$

Hence it appears that the product may be resolved into two squares, two different ways.

$$\begin{array}{rl}\text{Example,}\quad 5 &= 2^2+1^2\\ 13 &= 3^2+2^2\\ \hline 65 &= 8^2+1^2 \text{ or } 7^2+4^2\end{array}$$

Consequently, the products of three such numbers may be divided into two squares, four different ways, and so on.

3. The product of the sum of three squares by the sum of two squares, is the sum of four squares.

Or $(x^2+y^2+z^2)(x'^2+y'^2) \rightleftarrows (w''^2+x''^2+y''^2+z''^2$

For $(x^2+y^2+z^2)\ (x'^2+y'^2) =$

$$(x\,x'+y\,y')^2+(x\,y'-y\,x')^2+x'^2\,z^2+y'\,z^2$$

as will appear by performing the operation.

$$\begin{array}{rl}\text{Example,}\ 14 &= 3^2+2^2+1^2\\ 5 &= 2^2+1^2\\ 70 &= (3\cdot2+2\cdot1)^2+(2\cdot2-3\cdot1)^2+2^2+1^2\\ &= 8^2+1^2+2^2+1^2.\end{array}$$

4. The product arising from the multiplication of two numbers, each of which is the sum of four squares, is also itself the sum of four squares.

For $(w^2+x^2+y^2+z^2)\ (w'^2+x'^2+y'^2+z'^2) =$

$$(ww'+xx'+yy'+zz')^2+(wx'-xw'+yz'-zy')^2$$
$$+(wy'-xz'-yw'+zx')^2+(wz'+xy'-yx'-zw')^2$$

as will appear from the development of the formulæ.

5. The product of the two formulæ x^2-ay^2, and $x'^2-ay'^2$, is of the same form as each of them; that is

$$(x^2-a\,y^2)\ (x'^2-a\,y'^2) \rightleftarrows (x''^2-a\,y''^2)$$

For

$$(x^2-ay^2)(x'^2-ay'^2) = \begin{cases}(xx'+ayy')^2-a(xy'+yx')^2\text{, or}\\(xx'-ayy')^2-a(xy'-yx')^2\text{;}\end{cases}$$

and consequently,

$$(x^2-a\,y^2)\,(x'^2-a\,y^2) \rightleftarrows x''^2-a\,y''^2$$

6. The two formulæ $x^2+y^2+z^2$ and $x^2+y^2+2\,z^2$, are so related to each other, that the double of either

produces a quantity of the same form as the other. That is,

$$(x^2 + y^2 + z^2) \times 2 \backsimeq (x'^2 + y'^2 + 2z'^2)$$
$$(x^2 + y^2 + 2z^2) \times \backsimeq (x'^2 + y^2 + 2'^2)$$

For $(x^3 + y^2 + z^2) \times 2 = 2x^2 + 2y^2 + 2z^2$
$= (x + y)^2 + (x - y)^2 + 2z^2$
And $(x^2 + y^2 + 2z^2) + 2 = 2x^2 + 2y^2 + 4z^2$
$= (x + y)^2 + (x - y)^2 + (2z)^2$
For example, $14 = 3^2 + 2^2 + 1^2$

$$\begin{array}{ll} \text{Mult. by} & 2 \\ \hline \text{The product} & \left\{ \begin{array}{l} 28 = (3 + 2)^2 + (3 - 2)^2 + 2 \cdot 1^2 \\ \quad = 5^2 + 1^2 + 2 \end{array} \right. \\ \text{And} & 15 = 3_2 + 2^2 + 2 \cdot 1^2 \\ \text{Mult. by} & 2 \\ \hline \text{The product} & \left\{ \begin{array}{l} 50 = (3 + 2)^2 + (3 - 2)^2 + 4 \cdot 1^2 \\ \quad = 5^2 + 1^2 + 2^2 \end{array} \right. \end{array}$$

and the same of all other numbers of these forms.

7. The formulæ $x^2 - 2y^2$, may be always transformed into another of the form $2y'^2 - x^2$, and the latter may be transformed into the former.

For $x^2 - 2y^2 = 2(x \pm y)^2 - (x \pm 2) y^2 \backsimeq 2x' - y'^2$
And $2x^2 - y^2 = (x \pm 2y)^2 - 2(x \pm y^2 \backsimeq x'^2 - 2y^2$;

as will be seen by performing the operations; therefore a number, which is of one of those forms, is also of the other form.

Thus $14 = 2 \cdot 3^2 - 2^2 = 4^2 - 2 \cdot 1^2$
And $28 = 6^2 - 2 \cdot 5^2 - 2 \cdot 4^2 - 2^2$;

and the same is obviously true by all other numbers of these forms.

In the same manner it may be shown, that every number of the form $x^2 - 5y^2$, is also of the form $5x'^2 - y'^2$; and the latter is of the same form as the former; and generally,

8. If a be a number of the form $b^2 + 1$, then will the formulæ $x^2 - ay^2$ be resolvable into another of the form $ax'^2 - y'^2$; and conversely, the latter may be reduced to the former; that is

$x^2 - (b^2 + 1)y^2 \backsimeq (b^2 + 1)x'^2 - y'^2$. and
$(b^2 + 1)x^2 - y^2 \backsimeq x'^2 - (b^2 + 1)y'^2$
For $x^2 - (b^2 + 1) y^2 =$
$$(b^2 + 1)(x \pm by)^2 - \left\{ bx \pm (b^2 + 1) y \right\}^2$$
And $(b^2 + 1) x^2 - y^2 =$
$$\left\{ (b^2 + 1) x \pm by \right\}^2 - (b^2 + 1)(bx + y)^2$$

The first of which transformed formulæ is of the form $(b^2 + 1) x'^2 - y'^2$, and the latter of the form $x'^2 - (b^2 + 1) y'^2$.

This general proposition furnishes us with many particular cases; which have the remarkable property of being reciprocally convertible from the one form to the other; such are,

$$\left\{ \begin{array}{l} x^2 - 2y^2 \\ 2x^2 - y^2 \end{array} \right. \qquad \left\{ \begin{array}{l} x^2 - 5y^2 \\ 5x^2 - y^2 \end{array} \right.$$
$$\left\{ \begin{array}{l} x^2 - 10y^2 \\ 10x^2 - y^2 \end{array} \right. \qquad \left\{ \begin{array}{l} x^2 - 17y^2 \\ 17x^2 - y^2 \end{array} \right.$$
&c. &c.

The above properties find a very pleasing application in the solution of various diophantine problems.

Forms and Properties of Divisors.

(13.) In the preceding article we have investigated the forms of products, arising from multiplying together numbers of particular and specified forms; our object now is, to ascertain what must be the nature of a numerical formula, in order that it may divide a number of a given form; we cannot, however, in this case, as in that, enter into a complete investigation of the several theorems, as that would carry us far beyond our proper limits; we must therefore be contented with stating results, and referring for their demonstrations to those works wholly devoted to such inquiries, viz. Legendre; "*Sur la Theorie des Nombres.*" Gauss, "*Disquisitiones Arithmeticæ,*" and to Barlow's "*Elementary Investigation of the Theory of Numbers.*"

Proposition 1. Every divisor of the formula $t^2 + au^2$, t and u being numbers prime to each other; and a any integral number whatever, positive or negative, is also a divisor of the formula $q^2 + a$.

Consequently, if a number p is not a divisor of the formula $q^2 + a$, where there is only one indeterminate square, it cannot be a divisor of the more general formula $t^2 + au^2$, in which there are two indeterminate squares prime to each other.

2. Every divisor of the formula $t^2 + au^2$, in which t and u are prime to each other, is of the form $py^2 + 2qyu + ru^2$, and in which formula $prq^2 = a$ and $2q \angle p$ and $\angle r$, or at least not greater than either of them. Therefore, in assaying the divisors of any number of the above form, it will be sufficient for us to employ only such numbers as are contained in the latter formula.

3. Every divisor of the formula $t^2 + u^2$, t and u being prime to each other, is of the same form; that is, the sum of two squares, prime to each other, can only be divided by numbers which are also the sums of two such squares. For example, 65, which is the sum of two squares, prime to each other, can only be divided by 5 and 13, which are both the sums of two squares.

4 Every divisor of the formula $t^2 + 2u^2$, t and u being prime to each other, is also of the same form; that is, a number which is equal to the sum of a square and double a square, can only be divided by numbers which are equal to the sum of a square and double a square. Thus,

$$99 = 1 + 2 \cdot 7^2$$
Can only be divided by
$$\begin{array}{r} 3 = 1^2 + 2.1^2 \\ 9 = 1^2 + 2.2^2 \\ 11 = 3^2 + 2\,1^2 \\ 33 = 5^2 + 2\,2^2 \end{array}$$

And it is the same with every number contained under the above form.

5. Every divisor of the formula $t^2 - 2u^2$, t and u being prime to each other, is also of the same form; that is, a number which is equal to the difference of a square and double a square, prime to each other, is itself equal to the difference of a square and double a square.

For example, $98 = 10^2 - 2.1^2$, can only be divided by

$$\begin{array}{r} 2 = 2^2 - 2\,1^2 \\ 7 = 3^2 - 2.1^2 \\ 14 = 4^2 - 2.1^2 \\ 49 = 9^2 - 2.4^2 \end{array}$$

and the same of all other numbers of this form.

6. Every odd divisor of the formula $t^2 + 3u^2$, is of the same form as itself; and

7. Every odd divisor of the formula $t^2 - 5u^2$, is also of the same form as itself.

Thus $133 = 5^2+3.6^2 = 7.19$, and
$7 = 2^2+3.1^2$, $19 = 4^2+3.1^2$
Also $95 = 10^2 - 5.1^2 = 5.19$
$5 = 5^2 - 5.2^2$, and $19 = 7^2 - 5.2^2$

Remark. It frequently happens, that a number falls under two or more of the above forms; in which cases, its divisors are also of the same double and treble forms. And in some cases we have numbers belonging to each of the above forms.

Thus $241 = 15^2 + 4^2 = 13^2 + 2.6^2 = 21^2 - 2.10^2$
$= 7^2 + 3.8^2 = 31^2 - 5.12^2$

Quadratic forms of Prime Numbers.

(14.) We have seen that all square numbers are of one of the forms $4n$, $8n+1$; and hence we may establish at once the following theorems:

1. Every odd number represented by the formula
$$y^2+z^2 \Supset 4n+1$$
2. Every odd number represented by the formula
$$y^2+2z^2 \Supset 8n+3$$
3. Every odd number represented by the formula
$$y^2-2z^2 \Supset 8n+7$$

And from these arise, by way of exclusion, the three following:

4. No number of the form $4n-1$, can be represented by the formula y^2+z^2.

5. No numbers of the form $8n+5$, or $8n+7$, can be represented by the formula y^2+2z^2.

6. No numbers of the form $8n+3$, or $8n+5$, can be represented by the formula y^2-2z^2.

The above theorems apply to every odd number; but the following belong exclusively to prime numbers:

1. Every prime number of the form $4n+1$, is the sum of two squares, or is contained in the formula x^2+y^2.

Thus 5, 13, 17, 29, 37, and 41, are prime numbers of the form $4n+1$; and each of them is the sum of two squares: thus,

$5 = 2^2+1^2$ $\quad$ $29 = 5^2+2^2$
$13 = 3^2+2^2$ $\quad$ $37 = 6^2+1^2$
$17 = 4^2+1$ $\quad$ $41 = 5^2+4^2$

and so on for all other prime numbers of this form.

2. Every prime number $8n+1$ is of the three forms y^2+z^2, y^2+2z^2, and y^2-2z^2.

Thus $41 = 5^2+4^2 = 3^2+2.4^2 = 7^2-2.2^2$
and $73 = 8^2+3^2 = 1^2+2.6^2 = 9^2-2.2^2$
and so on with all prime numbers of the form $8n+1$.

3. Every prime number $8n+3$ is of the form $y+2z^2$

Thus 11, 19, 43, and 59, are prime numbers of this form, and $11 = 3^2+2.1^2$; $19 = 1^2+2.3^2$
$41 = 5^2+2\,3^2$; $59 = 3^2+2.5^2$
and so on for all prime numbers of the form $8n+3$.

4. Every prime number $8n+7$ is of the form y^2-2z^2.
Thus $31 = 7^2-2.3^2$, and $47 = 7^2-2.1^2$
and so on for all prime numbers of the form $8n+7$.

From the above proportions, it follows, that

5. That all prime numbers of the form $8n+1$, and $8n+5$, are, exclusively of all others, contained in the formula y^2+z^2.

6. All prime numbers of the form $8n+1$, and $8n+3$, are, exclusively of all others, contained in the formula. y^2+2z^2.

7. All prime numbers of the form 8^n+1, and $8n+7$, are, exclusively of all others, contained in the formula y^2-2z^1.

8. All prime numbers of the form $8n+1$, are at the same time of the three forms
$$y^2+z^2,\ y^2+2z^2,\ y^2-2z^2.$$

By means of the above propositions, we may ascertain whether a given number be a prime by subtraction, instead of the usual laborious operations by division.

Notation, different Scales, &c.

15. Our first ideas of numbers are so interwoven with the usual mode of expressing them by means of our numeral digits, that unless our attention be particularly directed to the inquiry of its merits, we are likely to pass it over as a matter of course, without ever being aware of the numerous advantages which the sciences derive from this simple but happy invention. For want of it, the Greeks, and all the more ancient people, were much embarrassed in their arithmetical calculations, and very limited in their mode of expression. With 36 different characters, the Greeks were at first only able to express those numbers which were less than a 10000; and even within this limit, their arithmetical operations, such as multiplication, division, extracting the square root, &c. were attended with great labour and complication; in short, it is not too much to say, that every branch of mathematics, with the exception of pure geometry, has derived more advantages from this simple contrivance, than from any other individual discovery in the entire circle of the sciences.

The great merit of this mode of expression does not, however, depend upon the particular scale, or division of numbers into periods of 10, which is common to nearly every known nation of the globe, because other scales might have been employed which possess equal, if not superior advantages, but to the thought of giving to every digit a local as well as its natural value, which might still have been employed, whatever number had been assumed as the radix of the system.

This will appear from the following proposition:

1. Every number N may be reduced to the form
$$N = a r^n + b r^{n-1} + c r^{n-2} + \&c.\ p r^2 + q r + w,$$
where r may be any number whatever, and a, b, c, &c. integers less than r.

For conceive N to be divided by the greatest power of r contained in it, as r^n, then the quotient a will be less than r, and let the remainder be N'; and we shall have
$$N = a r^n + N'.$$
In the same way, we may reduce N' to the form
$$N' = b r^{n-1} + N'', \text{ or}$$
$$N = a r^n + b r^{n-1} + N''.$$
In the same manner divide N'' by the greatest power of r contained in it, as r^{n-2}, and let the quotient be c, and remainder N''', and we shall thus have
$$N = a r^n + b r^{n-1} + c r^{n-2} + N''';$$
and proceeding thus till the remainder is less than r, as w, the number will be reduced, as stated in the proposition to the form
$$N = a r^n + b r^{n-1} + c r^{n-2} + \&c.\ p r^2 + q r + w,$$
where b, c, p, &c. are either zero, or less than r.

If $r = 10$, then a, b, c, &c. are the digits by which a number is expressed in our common system of notation: thus

$$76034 = 7.10^4 + 6.10^3 + 0.10^2 + 3.10^1 + 4$$
$$18461 = 1.10^4 + 8.10^3 + 4.10^2 + 6.10^1 + 1$$

which form is always understood in enumerating the value of any number; that is, we give in every digit a local, as well as a natural or integral value, and in this contrivance consists the advantages to which we have alluded.

It is evident, that in the same manner we might employ any other number as well as 10 for the radix of a system of notation, as 2, 3, 4, &c. and accordingly as we use these numbers the scale of notation receives the following denomination, viz. with the

Radix $r=2$ it is termed the binary scale.
$r=3$.........................ternary scale.
$r=4$.........................quarternary.
$r=5$.........................quinary.
$r=6$.........................senary.
&c. &c.
$r=10$.........................denary, or common scale.
$r=12$.........................duodenary.

And in each of these scales, the number of different digits for expressing a proposed number is always equal to the radix of the system including the cipher.

2. To transform a given number from the common scale to any other proposed; or, which is the same, to convert a given number into the form

$$N = ar^n + b\,r^{n-1} + c\,r^{n-2} + \&c.\ p\,r^2 + q\,r + w$$

r having any proposed value.

It is obvious, that if we divide the above formula by r, we shall have for our quotient

$$a\,r^{n-1} + b\,r^{n-2} + cr^{n-3} + \&c. p\,r + q,$$

and for our remainder w.

In the same way, this quotient divided by r will give a quotient

$$a\,r^{n-2} + b\,r^{n-3} + c^{r-4} +, \&c.\ r$$

with a remainder q; and by proceeding thus as long as division can be made, we shall have in succession, for our remainders, w, q, p, &c. c, b, and a; which are the digits of the number in an inverted order; consequently those digits with their proper order become known.

Exam. 1. Convert 17486 into the senary scale.

Here, by the above proportion,

6)17486
6)2914 rem. 2 = w
6)485 . . . 4 = q
6)80 . . . 5 = p
6)13 . . . 2 = c
6)2 . . . 1 = b
0 . . . 2 = a

Hence 212542, in the senary scale, is equal to 17486 in the common scale.

Exam. 2. Transform 1810 into the binary and ternary scales.

Binary.	Ternary.
2)1810	3)1810
2)905 rem. = 0	3)603 = 1
2)452 . . . = 1	3)201 = 0
2)226 . . . = 0	3)67 = 0
2)113 . . . = 0	3)22 = 0
2)56 . . . = 1	3)7 = 1
2)28 . . . = 0	3)2 = 1
2)14 . . . = 0	0 = 2
2)7 . . . = 0	
2)3 . . . = 1	
2)1 . . . = 1	
0 . . . = 1	

Therefore 1810 = 11100010010 in the binary scale.
and 1810 = 2111001 in the ternary scale,

Since it appears that the number of digits in each scale must be equal to the number expressing the index, we must, for the duodenary scale, have two additional characters for expressing 10 and 11, which we may do as follows: $\varphi = 10$, and $\pi = 11$.

Example 3. With these additional characters convert the numbers 347656 and 215855 into the duodenary scale.

12)347656	12)215855
12)28971—4	12)17987—11 = π
12)2414—3	12)1498—11 = π
12)201—2	12)124—10 = φ
12)16—9	12)10— 4
12)1—4	0—10 = φ
0	

Hence 347656 = 149234 }
and 215855 = $\varphi\,4\,\varphi\,\pi\,\pi$ } in the duodenary scale.

3. To convert a number out any other scale into the denary or common scale.

This may be still effected in the same manner, by dividing the number successively by 10; but, in performing this, it is requisite to bear well in mind the radix of the proposed system, so as to give a proper value to every dividend in succession, by multiplying each leading digit by the index, and adding the next digit as units, which is perhaps a little embarrassing: it will therefore be best to perform the operation as follows.

Example 1. Let it be required to convert the number 212542 in the senary scale into the common scale.

Here $212542 = 2.6^5 + 1.6^4 + 2\,6^3 + 5.6^2 + 4.6^1 + 2$.

Therefore $2.6^5 = 15552$
$1.6^4 = 1296$
$2.6^3 = 432$
$5.6^2 = 180$
$4.6 = 24$
$2 = 2$

Hence 212542 = 17486 in the denary scale.

Our common rules for performing operations in what is called duodecimals, is a mixture of the denary and duodenary scales; viz. the parts less than feet are expressed according to the duodenary system, but the feet in the decimal or denary. But by first changing the number of feet into the duodenary scale, all the operations are much simplified, and the results obtained with much less labour, as appears in the following examples.

Exam. 1. Multiply 17 feet 3 in. 4 pts. by 19 feet 5 in. 11 pts.

	Ft.	In.	Pts.
Here 15.34 =	17	3	4
17.5π =	19	5	11

13φ08
7248
φ0π4
1534

240·9688 = 336 ft. 9′ 6″ 8‴ 8^{iv}.

Exam. 2. The area of a rectangle is 336 ft. $9'\ 6''\ 8'''\ 8^{iv}$, and the breadth is 17 ft. 3 in. 4 pts. Required the length.

Here 336 ft. $9'\ 6''\ 8'''\ 8^{iv} = 240.9688$, and 17 ft. $3'\ 4'' = 15.34$ in the duodenary scale; wherefore

$$\begin{array}{l} 1534)240.9688(17.5\pi = 19 \text{ ft. } 5'\ 11'' \\ \quad\quad 1534 \\ \quad\quad \overline{} \\ \quad\quad \phi 856 \\ \quad\quad \phi 0\pi 4 \\ \quad\quad \overline{} \\ \quad\quad 7628 \\ \quad\quad 6248 \\ \quad\quad \overline{} \\ \quad\quad 13\phi 08 \\ \quad\quad 13\phi 08 \end{array}$$

Besides the simplicity of this mode of operation, it has also the advantage of being proved by casting out the 11's from the factors, the same as we do the 9's in our common operations; for in every scale this property holds good, provided we employ a number 1 less than the radix of the system, as will appear from the following propositions.

4. In any scale of notation, if the sum of the digits by which a number is expressed be subtracted from the number itself, the remainder will be divisible by the radix minus 1.

Let $N = a r^n + b r^{n-1} + c r^{n-2} +$, &c. $p r^2 + q r + w$ represent any numbers, $a + b + e +$, &c. $p + q + w$, being the sum of its digits. Then, by subtracting these from the former, we have

$(a r^n - a) + (b r^{n-1} - b) + (c r^{n-2} c) +$, &c. $(p r^2 - p) + (q r - q)$, which is equal to

$a\ (r^n - 1) + (r^{n-1} - 1) + c(r^{n-3} - 1) + p\ (r^2 - 1) + q\ (r - 1)$;

and since the difference of any two powers is divisible by the difference of their roots, it is evident that each of those terms is divisible by $r - 1$; and consequently the whole expression is divisible by the same.

Hence any number divided by one less than the radix of the system, will leave the same remainder as the sum of the digits by which the number is expressed, when divided by the same divisor.

Thus in our common scale of notation, a number divided by 9, and the sum of its digits divided by 9, will leave the same remainder; and in the duodenary scale, a number divided by 11 will leave the same remainder as the sum of its digits divided by 11; and so on for any other scale or system.

This constitutes the basis of our method of proving multiplication by casting out the nines from the two factors, and from the product; and from the sum of the digits in each factor and from their product, which ought to leave the same remainder as in the former case, when the operation is correct.

Let M and N represent any two factors, and m and n the sum of the digits of each; then, from what has been shown above, we shall have

$$M = 9a + r \qquad \text{also } m = 9a' + r$$
$$N = 9b + s \qquad\qquad n = 9b' + s$$

Hence $MN = 81ab + 9br + 9as + rs$,

And $mn = 81a'b' + 9'br + 9a's + rs$.

Consequently each of these products, when divided by 9, will leave the same remainder; and the same is obviously true of every system by using a number equal to the radix minus 1.

We might have extended these researches to a much greater length, if the nature of our work would have admitted of it: as this is not the case, we must be satisfied with referring those who are desirous of farther information on this subject, to the works quoted in various parts of this article.

NUMERATION. See Arithmetic.

NUMIDIA, in ancient geography, was a country in the north of Africa, which, according to Strabo, comprehended the kingdoms of the Massyli and Massæsyli. It is now occupied by the kingdoms of Algiers and Biledulgerid, already described.

NUMISMATOLOGY.

Numismatology, (from Νομισμα, a coin or piece of money, and Λογος, a discourse,) is that branch of historical science which treats of coins and medals. The study of numismatology, especially of ancient coins and medals, is of singular importance in illustrating the history, chronology, geography, mythology, as well as the manners and customs of the states of antiquity. The historical evidence which they afford is superior to every other, because their testimony is contemporaneous; and, unlike the works of ancient authors, they are not liable to be corrupted by the negligence of transcribers. Coins and medals also afford us a pretty certain criterion of the progress of the fine arts at different periods, and among various nations. Thus we are enabled to determine, not only from historical records, but likewise from an examination of ancient coins, that the golden age of the arts in Greece commenced about the time of Philip II. of Macedon, that it continued under the reign of his son, Alexander the Great, and maintained itself for a considerable period under his successors. Farther, history gives us little information with respect to the state of the arts in several ancient countries, such as Magna Græcia, Sicily, &c. while with regard to others, such as Bœotia, Bithynia, &c. historical testimony seems to deny them all pretension to taste. But we know from existing monuments, that in Magna Græcia, and Sicily, the arts must have flourished in a very high degree, for even their coins in most common use are executed in a style of singular beauty. From the same source we learn that the natives of Bœotia and Bithynia, as well as the more celebrated states of Greece, possessed a fine feeling of all that is beautiful in art.

But this taste prevailed not merely in the larger cities of Greece, where it might be fostered by wealth and luxury; it extended to their remotest colonies, and their most insignificant communities. How unimportant, for example, is the history of Sybritia, one of the smallest towns in Crete! Yet the coins struck there will stand a comparison with the finest that ever were executed in Greece. The same may be said of the Ionian colony which established itself in Gaul, and founded the town of Marseilles; of the Cyreneans in Africa, and of the Macedonian colony which Alexander the Great left behind him in Bactriana.

After the conquest of Greece by the Romans, and the transference of its treasures to Rome, the arts and sciences in the former country rapidly declined. This is easily observable in the state of their coinage during the period of the Roman emperors, which scarcely affords a trace of the pure tase which had been previously exhibited by that ingenious people in the fine arts. The Greek artists emigrated to Rome, where they sought that encouragement which was no longer to be found in their own country; and the arts revived and flourished once more amidst the wealth and luxury of the capital of the western empire. So long as Rome preserved its internal strength and independence, its coinage was, for the most part, exceedingly beautiful. This period commenced about the latter days of the republic, and continued down to the reign of the Emperor Commodus. From that time, however, the art gradually declined, until, under the last emperors, the taste displayed in their coinage became perfectly barbarous.

Ancient coins have been found buried in the earth, at various times, in considerable quantities. In Sicily, the silver coins with the head of Proserpine, are said to have been found in such numbers as to weigh 600 French livres. In the sixteenth century, 60,000 Roman coins were found at Modena, supposed to have been a military chest hid after the battle of Bedriacum, when Otho was defeated by Vitellius. Laz, a trust-worthy author of Vienna, mentions that, in his time, that is, in the reign of the Emperor Ferdinand I. there was found buried in a river in Transylvania, a treasure consisting of upwards of 40,000 gold coins, most of which bore the Greek name of the Thracian king Lysimachus. In the year 1760, near 30,000 Roman coins were found in earthen vessels, near Brest in Bretagne. By such accidental discoveries as these, such a surprising number of ancient coins has come into our hands, that it is easier to exhibit one hundred coins of Augustus, or Nero, or of Dyrrachium, a town once of no great importance in Illyria, than one of Charlemagne, or any of the other German emperors of the middle ages.

The most ancient coins, the antiquity of which can be ascertained, are those of some of the kings of Macedonia, of whom Alexander I. and Archelaus I. belong to the fifth century before Christ. At the same time, there is a great number of coins of towns, particularly in Magna Græcia and Sicily, which bear unquestionable traces of a much earlier origin. To these belongs the coin (Plate CCCCXX. Fig. 1.) which bears the impression of an ox, raised on one side, and hollow on the other; a style of coinage which appears to have prevailed in Magna Græcia in remote antiquity. The inscription VM points to those times when M was written instead of Σ, and V instead of Υ; and when the original oriental practice of writing from right to left was still retained. For VM is here the same as ΣΥ, the initial letters of the well-known town of Sybaris in Magna Græcia. But of this kind of coins nothing farther can be determined with precision, because they afford no chronological data to enable us to ascertain their exact age.

The ancient numismatology extends from the earliest times to the fall of the western empire; the numismatology of the middle ages commences with Charlemagne; and that of modern times with the emperor Maximilian I.

The subject of numismatology has been treated, either partially or at large, by various authors, such as Vaillant, Beauvais, Le Blanc, Banduri, Beger, Hancarville, Cooke, Sestini, Pinkerton, and others, to whose works we shall refer at the end of this article. But the most distinguished name in this science is undoubtedly that of Eckhel of Vienna, a man of profound learning and excellent judgment, who first reduced this branch of knowledge into systematic order, and whose methodical arrangement we propose to adopt, with some slight deviations, in the sequel.

Before proceeding, however, to the classification and description of ancient coins, it appears necessary, for the better understanding of the subject, that we should make some preliminary observations on the metals of which they were composed, their weight, value, and size, their names and denominations, the languages inscribed upon them, as well as upon the various methods of forging and imitating these interesting remains of antiquity.

The materials of which the ancient coins were composed were, as in modern times, gold, silver, and the various modifications of copper. The laws of Lycurgus also make mention of iron coins being introduced among the Spartans; and the same has been said of Byzantium. But experience has not confirmed this information; and even if it had been the case, it is not likely that coins of a metal so liable to be destroyed by rust, as iron, should have been preserved to modern times. All that remains to us of the ancient coinage, is composed of the three metals above mentioned; and that these were the only materials used, appears highly probable from numerous specimens of the coins of the emperor Augustus, on the reverse of which the *triumviri*, who had the superintendance of the mint, used to denominate themselves: IIIVIR.A.A.A.F.F. that is, *Auro Argento Aere Flando Feriundo.* (Plate CCCCXX. Fig. 2.)

Among the Romans and Greeks, the gold and silver was of the finest quality. Some important changes, however, took place in the Roman silver coinage: for its intrinsic quality became depreciated in proportion to the decline of the resources of the empire. From the time of the emperor Severus, the quantity of base alloy was considerable; and afterwards the copper came to predominate over the silver. These coins, therefore, were called *numi ærosi*, or *incoctiles*, on account of the great admixture of copper. From the time of Claudius Gothicus, to that of Dioclesian, silver coins are exceedingly rare; but it was common to wash over the brass or copper coins with silver.

The ancient brass coins consist partly of pure copper, and partly of a mixture of that with other metals. For a long period, antiquaries were accustomed to talk of coins of Corinthian brass; but this idea has been justly ridiculed by the more modern numismatologists, who assert that not one coin has ever been exhibited of this metal, which appears to have been employed only in the manufacture of statues, vases, and toys. It is certain, that upon analyzing some of those coins which were said to be of Corinthian brass, no traces of gold could be found.

As gold is not liable to be affected by rust, the coins of this metal, in general, are found in a state of excellent preservation. The silver coins have fared worse; but those of brass worst of all. A single circumstance, however, has frequently proved highly favourable to the coins of brass and copper; that is, when, by lying in a certain kind of soil, they have acquired a species of fine rust, like varnish, which is at once preservative and ornamental. This fine rust, says Mr. Pinkerton, which is indeed a natural varnish, not imitable by the art of man, is sometimes of a delicate blue, like that of a turquoise;

sometimes of a bronze brown, equal to that observable in ancient statues of bronze, and so highly prized; and sometimes of an exquisite green, a little on the azure hue, which last is the most beautiful of all. It is also found of a fine purple, of olive, and of a cream colour, or pale yellow, which last is exquisite, and shows the impression to as much advantage as paper of a cream colour, used in all great foreign presses, does copperplates and printing. The Neapolitan *patina* (the rust in question) is of a light green; and, when free from excrescence or blemish, is very beautiful. Sometimes the purple patina gleams through an upper coat of another quality, with as fine effect as a variegated silk or gem. In a few instances, a rust of a deeper green is found; and it is sometimes spotted with the red or bronze shade, which gives it quite the appearance of the East Indian stone, called the blood-stone. These rusts are all, when the real product of time, as hard as the metal itself, and preserve it much better than any artificial varnish could have done; concealing, at the same time, not the most minute particle of the impression of the coin.

With regard to the weight, value, &c. of the ancient coins, we shall speak first of the Roman, and afterwards of the Greek coinage.

According to the testimony of Pliny, the Romans first began to coin money in the reign of Servius Tullius. This coinage was entirely of copper or brass, and was estimated by weight. The regulating weight was the pound, (*as*, *libra*,) which was divided into twelve ounces. The half pound was called *semis*. The mark of a pound on a piece of money was a straight line, like the letter I.; that of a half pound S, being the initial letter of the word *semis*. The mark of an ounce was a small ball. If the piece contained 1, 2, 3, 4, or 5 ounces, this was designated by as many balls. For a considerable time, the *as*, whether considered as a pound, or as a piece of money, was of equal weight; but afterwards its weight, as money, gradually became much depreciated. The impression on the *as* was, on the one side, the double head of Janus, and on the other a ship. Plate CCCCXX. Figs. 3, 4, 5.

The Romans began to coin silver money a few years before the first Punic war. It consisted of the *Denarius*, *Quinarius*, and *Sestertius*. The *Denarius* was so called, because it contained *denos asses*, or ten pounds of brass; in like manner, the *Quinarius*, or half of the *Denarius*, contained the value of five pounds; and the *Sestertius*, or half of the *Quinarius*, two pounds and a half of brass. The mark of the *Denarius* was X. that of the *Quinarius* V. and that of the *Sestertius* IIS. Plate CCCCXX. Fig. 6, 7, 8. In the older times, all the three coins had the same impressions, viz. on the obverse, the winged head of Pallas, and, on the reverse, the mounted *Dioscuri*, or Castor and Pollux. But at a later period the subjects were chosen in an arbitrary manner, as we shall have occasion to show, when we come to treat of the coins of the Roman families. On the *Quinarii* there was generally impressed a goddess of victory, on which account they were frequently called *Victoriati*.

The Romans reckoned all their sums of money by sesterces; but the manner in which they expressed themselves was so confused, that for the better understanding of the ancient authors, it may be proper to lay down the three following rules. 1. When the word *sestertius* is used in the masculine gender, *e. g. trecenti sestertii*, the word *numi* is understood, and as many sesterces are meant as are expressed by the number: as in the present instance, 300. 2. When the word *sestertius* is used in the neuter gender and plural number, *e. g. trecenta sestertia*, in order to discover the sum meant to be expressed, we must multiply the number given by 1000; conseqently *trecenta sestertia* make 300,000 sesterces. When the word is used in the neuter gender and singular number, and the word denoting the number is formed by a termination in *ies*, *e. g. decies sestertium*, then the number must be multiplied by 100,000. *Decies sestertium*, therefore, means a million. In writing, these numbers are expressed thus: *IIS. trecenti*, or *IIS. trecenta*, or *IIS. decies*. But it is sometimes difficult to discover the number when it is expressed by means of letters. Thus, *IIS.CCC.* may be read in three ways: *sestertii trecenti*, *sestertia trecenta*, *sestertium trecenties*; and upon this ambiguity was founded the fraud, by which the emperor Tiberius deprived Galba of a rich legacy. Livia, the wife of Augustus, had written in her testament: Galba shall receive IIS.D.: by which she undoubtedly meant II.S, *quingenties*; but Tiberius, her son and heir, chose to read it, *sestertia quingena*. In general, however, the true reading can be easily determined by the circumstances. On a beautiful coin of the emperor Hadrian, there is represented a lictor, with the *fasces* in his left hand, and in his right a torch, with which he is setting fire to a heap of vouchers. Around is the following inscription: *Reliqua vetera*, *IIS.* Novies Millies Abolita; which means, that Hadrian had extinguished the remaining debt of the nation, to the amount of IIS. *novies millies*. Plate CCCCXX. Fig. 9.

It is difficult to ascertain the precise value of the Roman sestertius; but it is supposed to have been worth about two-pence of our money. Numismatologists, in general, have been in use to reckon the sestertius among the number of silver coins; but Mr. Pinkerton censures this idea, and contends, principally upon the authority of a passage from Pliny, that the sestertius was of brass. Is it not possible that the sestertius may have been coined at different times, both of silver and of brass; just as our copper coins of the present day were of silver in the reign of Henry VIII?

The general denomination of the silver money among the Greeks was the *drachma*, or eighth part of an ounce: which according to Mr. Pinkerton, was about nine-pence Sterling. The Roman *denarius*, although generally considered as equivalent to the Greek *drachma*, was only worth eight-pence. From the *drachma* were derived the *numi didrachmi*, *tridrachmi*, *tetradrachmi*—coins of the value of two, three, and four drachmas. The smaller silver coins were the *obolus*, *diobolus*, *triobolus*, and *hemiobolus*, &c. The most minute coin yet met with is the *tetraobolion dichalios*, or quarter *obolus*.

In Greece, large sums were reckoned by *Minæ* and *Talents*. The minæ contained 100 drachmas; and the talent 60 minæ; so that the talent contained 6000 drachmas. The mina is supposed to be a pound weight of the country to which it belonged. The standard of the talent varied in different countries.

Gold, according to Pliny, began to be coined at Rome about sixty-two years after the introduction of silver-money. During the period of the commonwealth the quantity was very inconsiderable; but it increased greatly from the time of Julius Cæsar downwards. The Roman *Aureus*, or gold coin, was of the value of 25 *denarii*, or 100 sesterces. Its weight and value, however, underwent several variations. Of the gold coinage of Greece little is known.

With respect to their size, brass coins were generally divided into three classes, corresponding, in some degree, to Nos. 3, 4, and 5, in Plate CCCCXX. They are called in Latin, *numi I. II. III. formæ*, or *moduli*. Those which considerably exceed the first size are called *Medallions*, *numi maximæ formæ*, or *moduli*. The same classification is also adopted in silver and gold coins.

Anciently, various names were given to different classes of coins, in consequence of particular circumstances. Many of them have been preserved by Julius Pollux; but we shall merely notice a few of them, which can be verified by an inspection of the coins themselves. They sometimes received their name from the image impressed upon them. Thus, the Athenian coins were called *owls*, because this bird was represented on their reverse, (Plate CCCCXXII. Fig. 41.) Hence, it was said of money concealed under the roof of a house; *multæ noctuæ sub ceramico* (*id est*, *tegulis*) *cubant*. For the same reason, there was a species of coin in the Peloponnesus which bore the name of *Tortoise*, (Plate CCCCXX. Fig. 10.) Hence the proverb—*virtutem et sapientiam vincunt testudines*. The Persians had an archer on their coins, (Plate CCCCXX. Fig. 11.) When Agesilaus, king of Sparta, attacked the Persians in Asia, the latter, by a secret distribution of money, induced the towns of Greece to declare war against the Spartans. Agesilaus being on this account obliged to retreat, he complained that 30,000 archers had forced him to quit Asia. In Asia Minor, there was a small silver coin which had the name of *Cistophorus*, because it was impressed with the mysterious Chest of Bacchus, (Plate CCCCXXI. Fig. 12.) The Romans had their *victoriati*, from the image of Victory; their *ratili*, from the image of a ship, (Plate CCCCXX. Fig. 3 ;) their *bigati* and *quadrigati*, from the impression of a two or four horse chariot.

Coins sometimes derived their names from the person who first caused them to be struck. Thus, Philip II. of Macedon introduced a gold coinage; and Darius, king of Persia, caused the *archers*, above mentioned, to be coined of gold and silver. Hence the *Philippi* and *Darics*, which are so often mentioned by the classical writers; corresponding, in some degree, to the modern *Louis-d'or* of France, the *Frederic d'or* of Prussia, the *Caroline* of Brunswick, &c.

Coins were occasionally named from some circumstance attending their form or workmanship. Thus the Romans had their *numi serrati*—coins of silver, so called because they were cut round the edge like a saw, (Plate CCCCXXI. Fig. 1.) It has been thought that the Romans introduced this practice, in order to frustrate the unlawful designs of the false coiners. At the same time, it may have been merely a fashion which prevailed for a time at Rome; for, at one period, saw-edged coins of brass were struck in Syria, which could not have been done with a view to prevent fraud. The *numi incusi* are such as have the same figure on both sides; on the one side raised, and on the other hollow. Of these there are two kinds. They are either intentionally hollow on one side—a practice which prevailed in many of the cities of Magna Græcia from the earliest times, as we have already observed with respect to a coin of Sybaris; or they have become so in consequence of an oversight of the artist, who had placed the coin to be struck above another coin, the impression of which had been communicated to the under part of the superincumbent metal. The *contorniati* were copper pieces of the medallion form, so called because of the hollow circle which runs round their edges. These were all fabricated at Rome, in the latter times; but instead of the heads of the emperors, they have frequently the portraits of foreign kings, or other celebrated personages of antiquity. The reverses exhibit a variety of images; most of them having a reference to the chariot races and public games. We have given a specimen of one of them in Plate CCCCXX. Fig. 12. which, on the obverse, exhibits the portrait and name of Alexander the Great, and on the reverse, Sylla, in the act of seizing some of the companions of Ulysses by the hair of the head, and dragging them out of the ship, according to the narrative of Homer. Numismatologists are not agreed as to the use and intention of this species of coins. The more probable opinion, however, is, that they had a reference of some kind or another to the Circensian games.

The ancient coins contain figures and inscriptions on their obverse and reverse. It seldom happens that the reverse is left quite blank. There frequently appears upon this side an irregular indentation, such as we formerly remarked in a coin of the Peloponnesus, Plate CCCCXX. Fig. 10.; and this is always a sign of high antiquity, before the art was known of communicating an impression to both sides of the coin; just as, in the infancy of printing, an impression was made only upon one side of the leaf.

The obverse generally exhibits the head, either of some divinity, or of an emperor, king, &c. The reverses present the most agreeable diversity of objects, which distinguish them advantageously from the current coins of the middle ages, and of modern times, so tiresome from their dry monotony. Yet several towns and sovereigns of antiquity were partial to some particular figure; as Athens to its Pallas and owl; Apollonia and Dyrrachium to their sucking calf; Sybaris to its ox looking backward; Alexander to the standing figure of victory, or the sitting Jupiter; Lysimachus, king of Thrace, to the sitting Pallas, &c. To these may be added certain national symbols. Thus, the Sicilian towns frequently exhibited their three human feet bound together, to represent the three promontories of their island, Pelorum, Pachynum, and Lilybæum, Plate CCCCXX. Fig. 28.; the Bœotians their shield, Plate CCCCXXII. Fig. 38.; the Macedonians their oval shields, set round in the form of a garland, Plate CCCCXXII. Fig. 37. Other nations represented some of the most remarkable productions of their country, *e. g.* Egypt, the crocodile; Phœnicia, the palm-tree; Cyrene, the precious plant, *laserpicium*. Sometimes, too, the Greeks chose such figures as contained a play upon the names of their towns. Thus Cordia, in Thrace, had a heart; Sidé, in Pamphylia, a pomegranate, Plate CCCCXX. Fig. 16.; the island of Rhodes, a rose, &c. It frequently happens, in these cases, that the name of the town is not even inscribed; the figure being left to speak for itself. The Romans, too, adopted this playful figurative language. Thus, Publicius Malleolus had upon his coins a hammer; Valerius Acisculus, a sort of pickax, which was used for splitting stones; Aquilius Florus, a flower: Furius Purpureo, the sea-cockle, from which the purple dye was prepared, &c. The favourite objects among the Greeks, for representing upon their coins, as well as in their other works of art, were their divinities, and every thing, indeed, which was connected with their religion. Among their religious exercises, too, may be reckoned their solemn games, to which they were passionately attached. These are often represented upon coins by means of a vessel surmounted by a branch of palm, as the prize of the victory. The species of games is always marked upon them, *e. g.* ΟΛΥΜΠΙΑ, ΠΥΘΙΑ, ΑΚΤΙΑ, &c. the Olympic, Pythian, Actian games, &c. A specimen of these will be found in a coin of Perinthus in Thrace. Plate CCCCXX. Fig. 13.

In the Roman coins, on the other hand, there is more of the historical and the symbolical. We shall have occasion to notice several specimens of the historical in the sequel. Their symbolical consisted in representing all the virtues, and indeed every thing that promotes human happiness, by an accurate and ingenious personification; by which means a collection of Roman coins appears highly imaginative and poetical. Thus, *Fortune* is represented as a woman, with a rudder in her right hand, and in her left a cornucopiæ; *Annona*, or the supply of provisions, is represented as a woman in a sitting posture, at whose feet stands a measure filled with ears of corn, and the prow of a ship; *Security* appears as a woman sitting in an arm-chair, carelessly supporting her head with her hand; *Eternity*, as a woman, who carries in her hands the sun and moon, or the phœnix, as emblems of eternity; and so forth.

The inscriptions give, as it were, animation to coins. They not only tell us when, where, and in whose honour they were struck; but likewise help to explain much that is otherwise dark and uncertain in antiquity. It were impossible, within any reasonable compass, to notice all the varieties of inscriptions. We shall merely advert to some of the more common and important.

The coins of the emperor Hadrian have the inscription, Hadrianus Augustus; those of king Demetrius, ΒΑΣΙΛΕΩΣ ΔΗΜΕΤΡΙΟΥ; those of Homer, ΟΜΗΡΟC, &c. By this fortunate circumstance, we receive either the true, or at least the ideal portraits of the great men of antiquity; for it is certain that the portraits of the sovereigns and philosophers of the earlier ages, such as Midas, Minos, Romulus, Homer, Pythagoras, &c. are equally imaginary with those of Jupiter, Apollo, and others. But still, ideal as they are, they were conceived by ancient artists, and in times of remote antiquity.

With regard to the names of the countries and towns where the coins were struck; we read upon those of the Macedonians ΜΑΚΕΔΟΝΩΝ; upon those of the Syracusans ΣΥΡΑΚΟΣΙΩΝ, &c. The situation of the towns is often determined by the neighbouring rivers, or mountains, or other circumstances. This is of great advantage when there are several towns of the same name, such as Laodicea. Thus, we know, that coins bearing the inscription ΔΑΟΔΙΚΕΩΝ. ΤΩΝ. ΠΡΟΣ. ΘΑΛΑΣΣΗ. belong to Laodicea in Syria, which was situated on the sea.

The Greek towns frequently showed their vanity by the adoption of certain titles of honour, the assertion of which, however insignificant, sometimes led to the most deadly enmities. The word *metropolis*, in its original and literal meaning, signified the relation of a particular town to others, which had sprung from it. Thus, Tyre was the metropolis, or mother town of Carthage; Corinth of Syracuse, &c. In this signification, Heraclea, a powerful town on the Black Sea, inscribed on its coins the following title, in the Doric dialect: ΜΑΤΡΟΣ. ΑΠΟΙΚΩΝ. ΠΟΛΙΩΝ,—mother of the colonial towns. On the other hand, these colonial towns sometimes acknowledged their origin, by adopting on their coins the symbols of their parent cities. Thus, Syracuse had a pegasus on its coins, because this was the acknowledged symbol of the parent city of Corinth. In later times, the word metropolis came to signify a city, which asserted an acknowledged precedence over other smaller towns within a certain district, and also exercised a species of jurisdiction; such as Antioch, in Syria; Cæsarea, in Cappadocia; Nicomedia, in Bithynia, &c. Some assumed the title of ΠΡΩΤΗ, the first, or principal town of a district.

The towns of Greece, and particularly those situated in Asia Minor, boasted much of the title of ΝΕΩΚΟΡΟΣ; and it is somewhat singular, that, even at this day, it has not been precisely ascertained what species of honour they attached to this strange title. The Greek word literally means nothing more than a person who is bound to keep the temple clean. But it must certainly have denoted some very high privilege, as it is often brought forward with much solemnity. Some towns boasted of having enjoyed this honour twice or three times: ΔΙΣ or ΤΡΙΣ ΝΕΩΚΟΡΩΝ. Nay, the Ephesians claimed still higher rank; and by the splendid inscription, ΕΦΕΣΙΩΝ. ΜΟΝΩΝ. ΑΠΑΣΩΝ. ΤΕΤΡΑΚΙΣ. ΝΕΩΚΟΡΩΝ.—proclaimed that they alone had four times received the neocorate.

Among other titles of towns, we find the following: ΑΥΤΟΝΟΜΟΣ, when a town possessed the privilege of being regulated by its own laws; ΕΛΕΥΘΕΡΑ, free, when the Romans had remitted the tribute in favour of a Greek town; ΙΕΡΑ, holy; or ΙΕΡΑ ΚΑΙ ΑΣΥΛΟΣ, a holy town, and an asylum. A town was called holy because of some divinity who was there principally worshipped, and who stood in general reverence. Thus Nicopolis in Epirus was holy on account of the temple of Apollo, and the Actian games which were celebrated there. Thus, too, on the Hebrew coins, Jerusalem is called *the holy Jerusalem*, as we shall afterwards see. An Asylnm, or place of refuge, was a town which had the privilege of protecting criminals who fled thither. ΝΑΥΑΡΧΙΣ was a title assumed by maritime towns, whose ports harboured a Roman fleet. Many Greek towns, and particularly the Asiatic, assumed the name of one or several emperors, either on account of some benefits conferred upon them, or from mere flattery. Thus, the city of Tarsus, in Cilicia, on several coins, is called by the names of ΑΔΡΙΑΝΗ, from Hadrian; ΚΟΜΜΟΔΙΑΝΗ, from Commodus; ΣΕΥΗΡΑΝΗ, from Severus; ΑΝΤΩΝΕΙΝΙΑΝΗ, from Antoninus Caracalla; ΜΑΚΡΕΙΝΙΑΝΗ. from Macrinus; and ΑΛΕΞΑΝΔΡΙΑΝΗ, from Alexander Severus.

The names and titles of magistrates frequently appear upon ancient coins of cities. These titles are various; such as ΑΡΧΩΝ, ΣΤΡΑΤΗΓΟΣ, ΠΡΥΤΑΝΙΣ, &c. and also Roman magistrates, who presided for a time over the government of a province, ΑΝΘΥΠΑΤΟΣ, *Proconsul;* or such as were devoted to the duties of religion, as ΙΕΡΕΥΣ, *Priest*, ΑΡΧΙΕΡΕΥΣ, *Arch-priest.*

Chronological dates on ancient coins are exceedingly useful to the philosopher, as they clear up many doubtful points in history. These consist principally in the year of a particular epoch, or of the reign of an emperor or king.

Next to the Olympiads, which, however, never appear upon coins, the principal epoch among the oriental Greeks was that of the Seleucides. Seleucus, one of the most distinguished generals of Alexander, possessed himself of the city of Babylon in the year 312 B. C. The most of the oriental Greeks began to compute from this period. After the whole known world had been subjected to the domination of Rome, many important events in the empire induced the Greeks to form new epochs. Thus, several Greek towns commenced a new computation from the date of the battle of Pharsalia, and that of Actium.

In their computations, the Greeks, after the primitive practice of the orientals, made use of the letters of their alphabet; out of which they formed Monads, Decades and Centenaries, (or units, tens, and hundreds,) in the following manner:

Monads:	A.	B.	Γ.	Δ.	E.	ϛ.	Z.	H.	Θ.
	1.	2.	3.	4.	5.	6.	7.	8.	9.
Decades:	I.	K.	Λ.	M.	N.	Ξ.	O.	Π.	9.
	10.	20.	30.	40.	50.	60.	70.	80.	90.
Cent.	P.	Σ.	T.	Y.	Φ.	X.	Ψ.	Ω.	λ.
	100.	200.	300.	400.	500.	600.	700.	800.	900.

The characters representing 6, 90, and 900, are not to be found in the present Alphabet. As every letter designates of itself a particular number, these three kinds of numerals may be transposed at pleasure. Consequently, to express the number 237, we may set down ΣΛZ, or ZΛΣ. On coins, the word ETOYΣ, *annus*, is generally prefixed to the numerical letter; or, instead of it, the letter L (the old form of the Greek *Lambda*,) as the initial letter of the word Λυκαβας, which also signifies *year*. Thus we read: ETOYΣ, or L. E.—L. ΛB.—L. Mϛ.—L. PNΘ.—in the year 5.—32.—46.—159.

The Romans, indeed, had a peculiar epoch of their own, namely, the building of their city, 753 years B. C.; but we know only a single coin in which it occurs. It has, upon the obverse, a head of the emperor Hadrian, and, upon the reverse, a woman sitting on the earth holding in her right hand a wheel, and with her left embracing three obelisks, with the inscription: *Anno* DCCCLXXIIII. *Natali Urbis Primum Circenses Constituti;* that is, *in the year of the building of Rome*, 874, *the Circensian games were first introduced in order to celebrate the birth-day of the city*. The obelisks represent the circus, which had three of them placed together at both ends, round which the chariots turned. The wheel represents the circus—*pars pro toto*. Plate CCCCXX. Fig. 14. In general, however, the Romans marked their dates by the names of their consuls; as the Greeks did by the names of their archons. On the coins of Dacia, and the colony Viminacium, the epoch is marked thus: ANNO V.—ANNO XI. &c. Plate CCCCXXI. Fig. 45.

On the Roman monuments, the years of the reign of their emperors are not immediately marked, but the number of the *tribunicia potestas*, which was renewed every year, and which, therefore, comes to the same thing. For when we read upon an imperial coin: *Tr. Pot. xx.* it means the 20th year of his reign. The Greeks, however, marked directly the years of the reign of the emperors, or of their kings: Thus, ETOYΣ, or L. Γ.—L. I.—or at full length, L. TPITOY. ΔEKATOY. *i. e.* in the third or tenth year of the reign. Of this description we have the beautiful and extensive collection of imperial medals, from Augustus to Dioclesian, which was struck at Alexandria in Egypt, and which have the year of the reign of the emperor inscribed upon them. Thus, on the reverse of a coin of Trajan, the river-god Nilus is represented in a recumbent posture, with a *cornucopia* in his right hand, and in his left a reed; under him is a crocodile, and at the very bottom L. Δ. signifying the 4th year of the reign. Above stands the number Iϛ. or 16, to denote that, in that year, the Nile had risen 16 ells. Plate CCCCXX. Fig. 15. But of this more hereafter.

Before leaving this part of the subject, it may be proper to say a few words respecting another species of coins, which have been called counter-marked, (*signa incusa.*) By this we understand a second, but in comparison much smaller impressions made at a later period, upon one or other of the sides of a coin already struck. These second impressions, or counter-marks, consist of figures or inscriptions, sometimes of both together. Two or three of them were sometimes struck upon the same side, often without the smallest regard to propriety, in so much that the finest portraits are frequently spoiled. An example of this will be found in the coin, Plate CCCCXX. Fig. 16. That this coin belongs to Sidé in Pamphylia, is evident from the pomegranate. In the middle of the countenance there is a small countermark, representing a bow and quiver, with the inscription: ΠEPΓA, being the first letters of the city of Pergamus in Mysia. The counter-marks on Roman coins consist, for the most part, merely of inscriptions; *e. g.* TI. AVG. or VES. IMP. that is, *Tiberius Augustus*, *Vespasianus Imperator*. They frequently exhibit the puzzling inscription, NCAPR, of which no antiquary has hitherto been able to give a satisfactory explanation. The probable reason for making these countermarks was to render a foreign coin current in the country into which it was introduced. Of another description are those medals which seem to have been re-coined, by making a fresh impression upon both sides. In them, the new stamp took effect only on the more prominent parts; and hence the deeper traces of the old coin are still perceptible. These coins are called, in Latin, *numi recusi.*

With regard to the languages used in the inscriptions on ancient coins, those most worthy of notice are the Phœnician, the Greek, and the Latin, not only because they appear upon the greatest number of ancient coins, but also because they were extensively employed in foreign countries. The Phœnician language was commonly used by the towns in Phœnicia, before it was expelled by the Greeks, under the successors of Alexander the Great, and afterwards. As the Phœnicians, in the most ancient times, carried on an extensive trade, their language was understood along the greater part of the coast of the Mediterranean. Indeed, we have coins of several towns of Spain, particularly of *Gades*, or Cadiz, which they founded, bearing Phœnician inscriptions. The Punic dialect, which was spoken at Carthage, also founded by a Phœnician colony, was a daughter of the Phœnician, and is found on the beautiful gold and silver coins which were struck in the Carthaginian portion of the island of Sicily. We have given a specimen of one of these in copper. Plate CCCCXX. Fig. 17. No great progress, however, has yet been made in explaining the inscriptions in these two languages.

The Greeks, originally a small tribe, whose proper country was bounded on the North by Thessaly, and on the south by the Peloponnesus, rapidly extended themselves in all directions. They first peopled all the islands of the Archipelago; then, proceeding farther, they occupied Sicily, the coasts of lower Italy, of Epirus, Illyria, Thrace, Asia Minor, and the Euxine sea, as far as Tauria and Colchis, with their colonial towns. In

Africa, they founded the splendid Cyrene; in Gaul, Marseilles; and in Spain, Emporia and Rhoda. Along with their religion, their manners, and their arts, they every where introduced their own language; and numerous specimens of the most ancient coins of all these colonies are still preserved. Hitherto, as we have seen, the Greeks contented themselves with occupying the coasts. But, in the course of time, Alexander the Great penetrated into the very heart of Asia, and proceeded in his wonderful career as far as India. The Macedonian generals, who divided his conquests amongst them after his death, introduced every where the Greek language; and from this period, the countries of Lydia, Phrygia, Cappadocia, Syria, Phœnicia, Egypt, and even some of the provinces situated beyond the Euphrates and Tigris, employed this language in the inscriptions on their coins.

The orthography of the Greek language suffered many changes, from the period when Cadmus introduced the Phœnician alphabet, to the time of Alexander the Great. Without being aware of this, we should often be liable to commit mistakes in reading the inscriptions upon ancient coins. Thus, the word HIMERA, which occurs upon the most ancient coins of the town of Himera in Sicily, (Plate CCCCXX. Fig. 18,) might easily be taken for Latin; while, in reality, it is genuine, though old, Greek. For among the most ancient Greeks the H, before it came to denote the long E, was, as in Latin, an aspirate; and the old Greek *Rho* was perfectly similar to the Roman R. The mode of writing IMEPA, therefore, is more modern. Many such examples are to be found upon coins; and they confirm what Pliny asserts, viz. that the most ancient Greek characters were the same as the Roman.

At first, only the Roman coins were inscribed with the Latin language. But when the Romans, in the course of time, sent out colonies into the conquered provinces, they made their own language predominant. In Corinth, for example, as soon as it was converted into a Roman colony by Julius Cæsar, the money was coined with Latin inscriptions, although this town was situated in the centre of Greece. With this exception, however, the Romans left the Greek cities full liberty to retain their own language on their coins. During the decline of the empire, the Greek cities ceased to coin money; and afterwards certain towns were appointed to coin money for the use of the provinces, and the pay of the soldiers, and upon these coins the Latin language alone was employed.

The other languages anciently used upon coins in Europe were the old Spanish, of which the alphabet is unknown; and the old Gaulic, composed of Latin characters, frequently mixed with Greek, borrowed partly from the Romans, and partly from the Greek colonial town of Marseilles, in Gaul.

In Asia, the Hebrew language occurs upon the coins of Judea, which consisted of shekels, and their subdivisions. The inscriptions, however, are in the Samaritan character, as in the specimen we have given, Plate CCCCXX. Fig. 19. On the one side is represented a vase, with the inscription: *Shekel Israel*, "Shekel of Israel;" and on the other, a tripartite flowering sprig, with the words: *Jerusalem Kedoschah*, "Jerusalem the holy." All those shekels, bearing an Hebrew inscription in Assyrian characters, such as are used in the printed Bibles, are entirely modern forgeries. The inscriptions in the Parthian language, on the coins of the kings of Parthia, and the Persian on the coins of the kings of Persia, have not been explained by antiquarians.

In Africa, we have inscriptions in the Numidian language on the coins of Numidia, which perhaps has some affinity with the neighbouring Punic.

With regard to the imitations and forgeries of coins, these are either of ancient or of modern execution. The former are what we might call false or bad money: the latter have been executed with the view of passing for genuine antiques. The forgery, in ancient times, appears in coins of copper, iron, or lead, covered over, very artfully, with a fine coat of some more precious metal. On this account they are called *subærati*, or *pelliculati*; and the base metal, which constitutes the substance of the coin, is called *anima numi*. It is seldom that we find forgeries of this description in the gold coin, because the deception would be easily detected by the deficiency of weight. But the number of forgeries in the Greek and Roman silver coin is enormous.

An immense deal of ingenuity has been employed, in modern times, in counterfeiting ancient coins, so as to pass upon the inexperienced connoisseur for genuine antiques. He who is not aware, that since, in modern times, the monuments of antiquity began to be prized, not individuals only have devoted themselves to this trade, but that in Italy, France, and even in Asia, regular manufactories have been established for the fabrication of these articles, must naturally be astonished at the extraordinary number of these forgeries. And what is still more to be wondered at, not only have those rare pieces been imitated, the sale of which would necessarily insure a large profit; but even the most common coins have been frequently forged, which can be purchased every day for nearly their intrinsic value.

In executing these forgeries, two different modes seem to have been adopted. The artist either invented a coin which never had an existence, or he counterfeited a real antique. To the first class belong the coins of Julius Cæsar, with the inscription *Veni, Vidi, Vici*; those of the queen Artemisia with her Mausoleum; of Dido with the city of Carthage; the heads of Miltiades, Themistocles, &c. A very superficial knowledge of numismatological science will suffice to detect them. Much art and ingenuity has been employed upon the second species of forgeries. The most common method is, to form a mould from a genuine coin, and to pour into it liquid metal. But as all ancient coins, with very few exceptions, are struck from a die, all those which are thus cast may at once be declared to be forgeries. But this mode of fabrication is easily detected from the inequalities which are observable on the surface of a cast coin; for in coins struck from a die the surface is alwas perfectly smooth. Mr. Pinkerton mentions, that in order to obviate this, the small sand-holes in cast coins were filled up with mastic, the letters retouched with a graver, and the whole covered with varnish. But in gold and silver medals there can be no deception of this kind; and even in those of brass and copper the quality of the varnish betrays the imposition. On cast coins, too, the letters and figures are never sufficiently sharp, and on their edges may be observed marks of the file. As this kind of forgery, therefore, is easily detected, other methods have been adopted. A real antique has been taken, and, with the assistance of the graver, the head of an emperor, and the inscription, have been so altered, that a very common imperial coin has been converted into a rare and precious coin of some other emperor. Or two genuine antiques are sawed asunder through the middle, and the reverse of the one soldered to the obverse of the other. But the most ingenious device which has been fallen upon, is that of manufacturing false dies after genuine antiques,—a mode of forgery which was practised with great success in the 16th century, by Cavino and Bassiano of Padua, whose imitations are at this day held in high esteem, on account of their wonderful execution.

It would be endless to detail all the artifices which have been resorted to, with a view of imposing upon connoisseurs, by offering false antiques for sale. Those who wish for more information upon this subject, may consult Beauvais and Pinkerton. Nothing, however, can supersede correct knowledge and a practised eye. We would only caution ignorant collectors how they purchase a coin of Otho in brass, a coin of Pescennius Niger, or of Gordianus Africanus; for of these there are a thousand counterfeits for one genuine, and, as they are extremely rare, they are sold at a very high price.

ANCIENT NUMISMATOLOGY.

The ancient coins and medals are divided by Eckhel into two principal classes, of which the first comprehends those coins which were struck at Rome, or elsewhere, under the direction of the Romans; and the second, those which were struck in other countries, under the direction of foreign states. The first class is subdivided into two parts. The first contains the *consular coins*, that is, those which were struck during the time of the republic, under the Roman consuls, which have also been called *coins of families*, from having, for the most part, the name of some Roman family inscribed upon them. The second comprehends the *imperial coins*, that is, those which bear the portrait, or the name of an emperor, an empress, or some individual of the imperial family.

The second class contains the coins of foreign nations, cities, or republics, colonies, kings, or other princes, under various names.

CLASS I.

Of the Roman Coins.

PART I.

Of the Consular Coins, or Coins of Families.

On most of the silver coins which were issued during the republic, and even some of those under Augustus, we find the names of those individuals under whose superintendence they were struck. This class contributes much to illustrate the mythology, history, politics, antiquities, as well as the religious and profane ceremonies and usages of the Romans. The triumvirate, who had the charge of the mint, were at great pains to celebrate on medals the antiquity and great actions of their ancestors; of which we shall have occasion to notice various examples. The following are the principal pieces belonging to this class.

Gens Accoleia.

P. Accoleius, Lariscolus. *Three young women, whose metamorphosis into trees is just commencing.* Plate CCCCXX. Fig. 21.

This alludes to the story of three sisters of Phaeton, who, inconsolable at his violent and untimely death, were changed into trees. Accoleius, who caused this coin to be struck, here plays upon his surname, *Lariscolus*, which he had inherited from some one of his ancestors, who may have been celebrated for the cultivation of the larch tree.

Gens Æmilia.

M. Lepidus. An. XV. Pr. H. O. C. S.—*M. Æmilius Lepidus on horseback.* Plate CCCCXX. Fig. 22.

The inscription is to be explained thus: M. Lepidus Annorum XV. Prætextatus Hostem Occidit, Civem Servavit. *M. Lepidus, in the 15th year of his age, while yet clothed with the prætexta, slew an enemy, and saved the life of a citizen.* This requires no farther illustration.

Alexandrea. *The head of a woman, with a crown in the form of a tower.* (M. Lepidus, Pont. Max. Tutor Reg. S. C.) *Lepidus placing a garland on the head of a boy standing near him.* Plate CCCCXX. Fig. 23.

Ptolemy, king of Egypt, by his testament, appointed the Roman people to be the guardians of his son, a minor. The senate sent M. Æmilius Lepidus to Alexandria, to administer the guardianship in the name of the people. The head with the crown in the form of a tower, on the obverse, is the usual symbol of cities.

M. Scaur. Æd. Cur. Ex. S. C. *At the bottom*, Rex. Aretas. *King Aretas on his knees, holding, with his left hand, a camel by the rein, and in his right an olive branch.* Plate CCCCXX. Fig. 24.

Aretas, king of a part of Arabia, made frequent incursions into Syria. Pompey the Great despatched M. Æmilius Scaurus after him, who soon compelled him to make peace. The camel is the symbol of Arabia; the olive branch of peace.

Gens Antistia.

C. Antistius Vetus Foedus P. R. Cum. Gabinis. *Two men, dressed in the toga, with their heads covered, holding a sow over the altar. On the obverse is the portrait of Augustus.* Plate CCCCXX. Fig. 25.

This coin represents the manner in which the Romans formed alliances with other nations. They held in their hands a sow, called Jupiter to witness, and slew the animal with a stone. To this Virgil alludes:

> *Stabant, et cæsa jungebant fœdera porca.*

Livy describes this ceremony at great length. C. Antistius Vetus was sprung from a very ancient family of Gabii; which town the last king Tarquin took by stratagem, upon which a league was formed, as is represented on this coin.

Gens Carisia.

Moneta. *Head of Moneta.*) (T. Carisius. *An anvil, the cap of Vulcan, a pair of tongs, and a hammer.* Plate CCCCXX. Fig. 26.

Juno was called by the Romans *Moneta.* The head of *Moneta* on the obverse, and the instruments represented on the reverse, seem to allude to the operation of coining.

Gens Cassia.

Q. Cassius. *The veiled head of a woman, with the* *inscription* Vest.) (*The circular temple of Vesta, with a* sella curulis *in it; on the one side a pot, and on the other a tablet, with the letters* A. C. *written upon it.* Plate CCCCXX. Fig. 27.

This coin alludes to L. Cassius Longinus, an ancestor of L. Cassius, who obtained great celebrity as a judge. He was called *reorum scopulus*, the rock on which the accused split. He summoned two vestal virgins before the court, and condemned them. Hence the head of Vesta and her temple are represented on the coin. He was the author of a law, by which the citizens no longer gave their suffrages verbally, but by means of small tablets, on which the letter A. (*absolvo*,) or C. (*condemno*.) were written.

Gens Claudia.

Marcellus. Cos. Quinq. *Marcellus approaches a temple, bearing a martial pole.* Plate CCCCXX. Fig. 28.

M. Claudius Marcellus overthrew the Gallic general Virdomar in single combat, took from him his armour, and dedicated it to *Jupiter Feretrius*. This offering was called the *spolia opima*. Virgil, in his Æneid, has made honourable mention of this deed of Marcellus, (B. vi. v. 869.)

Gens Cornelia.

Felix. *A senator seated; a man kneeling, reaching him an olive branch; another man appears kneeling, with his hands bound behind his back.* Plate CCCCXX. Fig. 29.

L. Cornelius Sulla was called Felix, on account of his constant good fortune. This coin alludes to the delivering up of Jugurtha by king Bocchus.

Gens Herennia.

Pietas. *The head of a female.*) (M. Herenni. *A young man carrying his old father upon his shoulders.* Plate CCCCXX. Fig. 30.

At an eruption of Mount Ætna, two brothers, Amphinomus and Anapias, took their parents on their shoulders, and carried them out of the reach of danger. This act is often represented on the coins of Catania in Sicily, where it took place.

Gens Hostilia.

The heads of Pallor *and of* Pavor *on the* denarii *of* Hostilius Saserna. Plate CCCCXX. Figs. 31, 32.

Hostilius Saserna placed these two heads on his coins, in order to persuade the world that he was descended from king Tullus Hostilius, who, in the midst of a battle with the inhabitants of Veii, which assumed an unfavourable aspect, vowed to build a temple to Pallor and Pavor, who were afterwards worshipped as deities at Rome.

Gens Junia.

1. Brutus. *Head of L. Brutus.*) (Ahala. *Head of Ahala.* Plate CCCCXX. Fig. 33.

2. M. Brutus. Imp. Costa. Leg. *Head of M. Brutus.*) (L. Brutus Prim. Cos. *Head of L. Brutus with a wreath of oak.* Plate CCCCXX. Fig. 34.

3. Libertas. *A female head representing Liberty.*) (Brutus *The Consul appears between two Lictors, carrying their fasces; the* Accensus *goes before.* Plate CCCCXX. Fig. 35.

4. Brut. Imp. L. Plaet. Cest. *Head of M. Brutus.*) (Eid. Mar. *The cap of liberty between two daggers.* Plate CCCCXX. Fig. 36.

These four coins allude to M. Junius Brutus, who killed Cæsar, and perished at Philippi. The first piece presents us with the heads of L. Junius Brutus, (to whom M. Brutus traced his family,) who expelled Tarquinius Superbus from Rome; and that of Servilius Ahala, who, with his own hand, slew Sp. Melius, who aimed at the sovereignty. The second exhibits on one side the head of M. Brutus; and on the other that of L. Brutus, the first consul, who obtained this dignity through the expulsion of Tarquin. The third piece represents the manner in which the consuls appeared in public. The fourth alludes to the death of Cæsar, and preserves the very day on which it took place: Eid. Mar. the 15th of March. The cap is the symbol of liberty.

Gens Mamilia.

Head of Mercury.) (C. Mamil. Limetan. *Ulysses standing in the short habit of a pilgrim, with a staff in his hand, and at his feet a dog, who fawns upon him.* Plate CCCCXX. Fig. 37.

This alludes to the well-known story of Ulysses, as related by Homer. C. Mamilius placed the figure of Ulysses upon this coin, because he pretended to be sprung from that hero.

Gens Plautia.

L. Plautius. *A female mask with serpent hair.*) (Plancus. *The winged Aurora conducting the four horses of the sun.* Plate CCCCXX. Fig. 38.

The musicians who were employed at Rome during the public festivals, having been offended by the censor Ap. Claudius, withdrew from Rome to Tibur. As the Romans, however, were unwilling to dispense with them, the second censor, Plautius, brought them back by a singular stratagem. He repaired to Tibur, made acquaintance with them, invited them to a feast, and plied them so long and so hard with drink, that they at last lost all recollection. He then put a mask upon each of them, placed them altogether in a carriage, carried them to Rome, and left them in the open street. When they were discovered in this situation in the morning, the merriment was universal, the quarrel was made up; and, to commemorate this ridiculous scene, an anniversary festival was instituted in honour of Minerva. This coin, struck by L. Plautius Plancus, a descendant of the witty censor, alludes to the above incident. On one side of the coin is a mask; and on the other the figure of Aurora, to denote the time at which the above *denouement* took place.

Gens Pompeia.

Sex. Pom. Fostlus. *The twins, Romulus and Remus, suckled by the wolf under a fig-tree, on which three magpies are sitting; Faustulus, the herd, looks on with astonishment.* Plate CCCCXX. Fig. 39.

The story here alluded to is well known. This coin appears to have been struck by some supposed descendant of Faustulus; which name was sometimes written *Fostlus*, as *Claudius* and *Clodius*, *vinculum* and *vinclum*.

Gens Pomponia.

Hercules Musarum. *Hercules playing on the lyre.* Plate CCCCXX. Fig. 40.

Q. Pomponi. Musa. *One of the nine Muses represented with her attributes.* Plate CCCCXX. Fig. 41.

These coins contain a play upon the surname *Musa.* The first represents the *Hercules Musarum*, or *Musageta*, under which designation he was worshipped both in Greece and at Rome.

The other coins of Pomponius Musa represent the nine Muses in their order, and distinguished by their respective attributes. The most remarkable is *Urania*, from *ȣρανος, the heavens.* As the teacher of astronomy, she points with a rod to the celestial sphere.

Gens Roscia.

A female head covered with the skin of a goat; sometimes with the letters I. S. M. R.) (*A female in the act of feeding a serpent.* Plate CCCCXXI. Fig. 1.

The obverse exhibits the head of Juno, who was worshipped, under this form, chiefly at Lanuvium, but afterwards also at Rome. She was distinguished by the name of *Juno Sispita Magna Regina.* The reverse represents a priestess of *Juno Sispita*, whose duty it was, at certain times, to feed the serpent dedicated to this goddess. The whole ceremony is prettily described by Propertius. Book iv. El. 4.

Gens Servilia.

Floral. Primus. *Head of the goddess Flora, decorated with flowers.* On the denarii of C. Servilius. Plate CCCCXXI. Fig. 2.

The Romans held an annual festival in honour of Flora, instituted, according to the testimony of this coin, by C. Servilius. The inscription runs thus: C. Servilius Floralia Primus *fecit.* For an account of these games, see Ovid, *Fast.* l. V. v. 183.

Gens Tituria.

Sabin. *A bearded head, with the inscription* Ta.) (L. Tituri. *Two Roman soldiers in the act of carrying off the Sabine women.* Plate CCCCXXI. Fig. 3. On another coin, *Tarpeia sitting under a heap of shields, which two Sabines are throwing at her.* Plate CCCCXXI. Fig. 4.

Both of these coins allude to well-known events which took place during the infancy of Rome. The second represents the history of Tarpeia, daughter of the Roman general, who treacherously undertook to admit the Sabines into the citadel, on condition of obtaining that which they wore on their left arms, meaning their golden bracelets. The Sabines having obtained possession, in order to keep their promise, threw upon her —not their bracelets indeed, but—their shields, and in such numbers as completely covered her. The obverse of both coins exhibits the head of Tatius, king of the Sabines, with the letters Ta.; and L. Titurius Sabinus, who was of Sabine extraction, caused both stories to be represented on his coins.

CLASS I.

PART II.

Of the Imperial Coins.

The coins belonging to this division deserve the first rank in numismatology, not only on account of the great importance of their subjects, but also on account of their great variety, and the long period which they occupy. From the year 48 B. C. in which Julius Cæsar, by his victory of Pharsalia, laid the first foundation of the monarchy, until A. D. 476, when the western empire perished under the last emperor Romulus, there are 524 years; and if we reckon the eastern empire, which subsisted until 1453, when Constantinople was taken by the Turks under Mahomet II. we have a period of 1500, during which there is an almost uninterrupted series of coins and medals.

We should far exceed our limits, were we to attempt to enumerate and illustrate the whole of this series; and we shall therefore confine our remarks to a selection of the best pieces, and proceed no farther than the reign of the emperor Caracalla,—a period not only the most splendid of the empire, but most worthy of the attention of the numismatologist.

It may be proper to premise, that the Roman emperors reserved to themselves the privilege of striking gold and silver coins, and left the brass coinage to the senate. On the latter, therefore, we always meet with the letters S. C. *Senatus Consulto;* which are very seldom found on the coins of gold and silver.

Julius Cæsar.

After he had attained the supreme power, the senate allowed him to place his own portrait on coins—a privilege which had never before been enjoyed by any other individual in his lifetime. He appears with a lank countenance, and a bald head; on which last account he was permitted to cover his forehead with a wreath of laurel. Plate CCCCXXI. Fig. 5.

His titles were the following: 1. Pontifex Maximus, an honour which he purchased by the distribution of immense sums of money among the people. 2. Imperator. This title he bore, both on account of the victories he had achieved, and as possessing the highest authority in the republic. Even during the period of the commonwealth, a general, when he obtained a victory, received the title of *Imperator* immediately upon the field of battle. When frequently victorious, he was called *Imperator iterum*, *tertium*, *quartum*, &c. The successors of Julius Cæsar adopted the title in both of its significations. 3. Cos. i. e. *Consul.* In the year in which he was assassinated, he was consul for the fifth time. 4. Dictator. This most distinguished honour was conferred upon him by the senate after the battle of Pharsalia. In the last year of his life, he was acknowledged as Dictator Perpetuo. 5. Parens Patriæ. This flattering title was also conferred upon him by the the senate. Hence, his assassins were called *Paricidæ*, and the Ides of March, the day on which he was murdered, *Parricidium.*

The head of Venus.) (Cæsar. *Æneas holding in one hand the Palladium, or image of Pallas, and with the other his father Anchises on his shoulders.* Plate CCCCXXI. Fig. 6.

The Julian family at Rome claimed their descent from Julus, or Ascanius, the son of Æneas, whose grandmother was Venus; hence Julius Cæsar always carried the portrait of Venus in his ring; and on the day of the battle of Pharsalia, his watch-word was *Venus victrix.*

CLEMENTIAE CÆSARIS. *A Temple.* Plate CCCCXXI. Fig. 7.

Cæsar not only pardoned his enemies, when he got them into his power, but even conferred upon them honours and dignities. On this account the senate ordered a temple to be erected, in which he should be represented as a god, reaching his hand to the goddess *Clementia.*

DIVI. JULI. *The head of Cæsar with a Comet hovering over it.* Or, DIVUS JULIUS. *A Comet.* Plate CCCCXXI. Fig. 8.

On a number of coins, which were struck after his death, the epithet *Divus* is bestowed upon Cæsar. In point of fact, he was deified by a decree of the senate, on the motion of Mark Antony, and his adopted son Octavian, afterwards Augustus Cæsar. This honour the people readily allowed him, not only on account of his wonderful achievements, but in consequence of a comet having appeared for seven days, during the celebration of the funeral games which were held in honour of this great man. This comet was held to be nothing else than the soul of the departed hero, which had just been received into heaven. After the example of Cæsar, most of the emperors were deified after their death.

POMPEIUS MAGNUS.

MAG. PIUS. IMP. ITER. *The head of Pompey the Great.*) (PRÆF. CLAS. ET. ORAE. MARIT. EX. S. C. *Neptune standing with one foot upon a ship; on each side the pious brothers carry off their parents.* On another coin, *Scylla, surrounded with dogs, striking around her with an uplifted rudder.* Plate CCCCXXI. Fig. 9, 10.

After the death of Pompey the Great, his sons Cneius and Sextus continued the war on the part of the republic, but were vanquished by Cæsar at Munda. Sextus alone escaped, and concealed himself till the death of Cæsar, when he again came forward, fitted out a fleet, and so annoyed Mark Anthony and Octavian, that they were at length compelled to admit him into their alliance, and to give up to him Sicily, with the title *Præfectus classis et oræ maritimæ ex S. C.*

The obverse exhibits the head of the great Pompey; but the inscription relates to his son Sextus. He derived the name of *Magnus* from his father; that of *Pius* he adopted, under the pretext that he made war upon the enemies of his father, and afforded protection to those Roman citizens who were proscribed by the triumvirate. Hence the figure of the pious brothers. He assumed the title of IMPERATOR ITERUM, in consequence of his twofold victory over his antagonists. The figure of Neptune alludes to his naval victories over Octavian; and he publicly proclaimed himself as the son of Neptune. To commemorate his victory over Octavian in the Straits of Sicily, he caused the figure of the monster Scylla, as above noticed, to be struck on his coins.

M. ANTONIUS.

The history of this celebrated man is well known. The inscription on his coins is generally the following: M. ANTONIUS AUGUR IIIVIR. Reipublicæ Constituendæ. In the character of Augur, he is sometimes represented with his head veiled, and holding in his hand the LITUUS, or Augur's staff. The letters IIIVR. R. P. C. allude to the triumvirate of Anthony, Octavian, and Lepidus.

THE HEAD OF MARK ANTHONY.) (PIETAS. COS. *The figure of a woman, with a rudder in one hand, a cornucopiæ in the other, and a stork at her feet.* Plate CCCCXXI. Fig. 11.

The inscription on the reverse relates to Lucius, the brother of Mark Anthony. The word PIETAS was adopted by Lucius Antonius to denote his affection for his brother Marcus. The stork was the symbol of piety, or natural affection.

M. ANTONIUS. IMPERATOR CONSUL DESIGNATUS ITERUM ET TERTIUM. *The head of Anthony with a crown of ivy: a wreath of ivy also goes round the edge of the coin.* On the silver pieces, called *Cistophori.* Plate CCCCXXI. Fig. 12.

The ivy garland properly belongs to Bacchus; but as Anthony wished to be taken for Bacchus, it was placed round his coins out of flattery. For the same reason, the ivy garland was placed round the coins of Mithridates, king of Pontus. Plate CCCCXXIII. Fig. 4.

ANTONI. ARMENIA. DEVICTA. *The head of Anthony, with an Armenian crown behind it.*) (CLEOPATRÆ. REGINÆ. REGUM. FILIORUM. REGUM. *Head of Cleopatra with the prow of a ship.* Plate CCCCXXI. Fig. 13.

This alludes to the stratagem by which Anthony deprived Artavasdes, king of Armenia, of his crown, and placed his own son, by Cleopatra, on the throne.

OCTAVIANUS AUGUSTUS.

The names inscribed upon his earliest coins were generally, CÆSAR. IIIVIR. R. P. C. Somewhat later IMP. CÆSAR. DIVI. FILIUS.

ÆGYPTO. CAPTA. *A crocodile.* Plate CCCCXXI. Fig. 14.

This coin commemorates his conquest of Egypt; a crocodile having anciently been the symbol of that country.

In the year 27 B. C. the senate bestowed upon him the title of *Augustus.* (Greek Σεβαστος,) a name which had hitherto been applied only to sacred things. This title was subsequently assumed by all the emperors. Not long afterwards, the senate conferred upon him the *tribunitia potestas*, which was also assumed by his successors, who used it in marking the year of their reign; thus, TR. POT. II. III. IV. &c. After the death of Lepidus, he assumed to himself the important office of *Pontifex Maximus*, as did also the subsequent emperors; and hence the letters P. M. which so frequently occur upon their coins. At a later period, the senate gave him the title of *Pater Patriæ*, which was likewise adopted by most of his successors. His reign, commencing from the battle of Actium, continued forty-four years. Having left no issue, he was succeeded by his step-son Tiberius. The following are the most remarkable coins of this period.

CÆSAR. COS. VII. CIVIBUS. SERVATIS. *Head of Augustus.*) (AUGUSTUS. S. C. *An eagle holding in its claws a wreath of oak, behind two sprigs of laurel.* Plate CCCCXXI. Fig. 15.

Having conquered his enemies, and restored internal peace, the senate ordered laurel trees to be planted in front of the house of Augustus, in honour of his victories, and in the middle an oaken wreath, as a mark of the public security.

Actium. Imp. X. *Apollo in a long robe, with the lyre in his hand.* On others, Sicilia Imp. X. *Diana with her bow and arrow.* Plate CCCCXXI. Fig. 16, 17.

These two coins were struck to commemorate his victories. The first alludes to the battle of Actium, where Apollo had a temple; the second to the victory over S. Pompeius, near Artemisium, a place sacred to Diana.

Signis. Receptis. *A Parthian on his knees, delivering up a Roman Standard.* Or, Mars Ultor, holding in each hand a field ensign. Plate CCCCXXI. Fig. 18, 19.

Civibus. Et. Signis. Militaribus A. Parthis Recuperatis. *A triumphal arch.* Plate CCCCXXII. Fig. 20.

In the victory which the Parthians gained over M. Crassus, a number of prisoners and standards fell into their hands, and remained in their possession for thirty-three years, until Augustus, by threats, prevailed upon the Parthian king, Phraates, to restore them. Hereupon, Augustus built a temple to *Mars Ultor*, in which the recovered standards were placed.

A pillar, with the inscription S. P. Q. R. Imp. Cæsari. Quod. Viæ Munitæ Sunt Ex. Ea. Pecunia. Quam. Is. Ad. Ærarum Detulit. Plate CCCCXXI. Fig. 21.

This coin alludes to the improvement of the highways, which Augustus effected with the money levied from the enemy. The simplicity of the inscription has been much admired.

Imp. XI. *The sign Capricorn.* Plate CCCCXXI. Fig. 22.

It is represented as a goat before, and a fish behind. Properly speaking, it is the god Pan, who, when the gods, afraid of the giant Typhon, changed themselves into various animals, assumed this absurd form, and was transferred to the zodiac. This figure appears very frequently both in the Greek and Roman coins of Augustus, who was born under the sign of Capricorn.

As Augustus prevailed upon the senate to deify Julius Cæsar, his successor Tiberius conferred the same honour upon him. Hence, on the coins struck after his death, he often appears as a god, under the name of Divus. Augustus. Pater; and the temple built in honour of him sometimes appears upon the reverse.

M. Agrippa.

He was one of the most considerable men in the empire, and had performed singular service to Augustus in his wars with S. Pompeius and Mark Anthony. Augustus gave him his daughter Julia in marriage, and intended her two sons, Caius and Lucius, to be his successors in the empire; but these died young. After a career of great fame, Agrippa died, to the great grief of Augustus, and indeed of the whole empire.

M. Agrippa. L. F. Cos. III. *Head of Agrippa, adorned with a wreath of ships' prows.*) (s. c. *Neptune, holding a dolphin in his right hand, and the trident in his left.* Plate CCCCXXI. Fig. 23.

This coin alludes to Agrippa's naval victories. After the victory over S. Pompeius, Octavius presented him with a crown of ships' prows, called, in Latin, *navalis*, *classica*, or *rostrata*. Virgil takes notice of this in the viii. book of the Æneid.

> *Parte alia ventis et Dis Agrippa secundis*
> *Arduus, agmen agens, cui, belli insigne superbum,*
> *Tempora navali fulgent rostrata corona.*

Tiberius Nero.

He was the son of T. Claudius Nero, and of Livia, who was afterwards the wife of Augustus. After the death of the sons of Agrippa, he was adopted by Augustus as his son, and succeeded him in the empire. He reigned twenty-two years.

His usual titles on coins are: TI. Cæsar, Divi. Aug. F. Augustus. P. M. Cos. Imp. Tr. Pot. Plate CCCCXXI. Fig. 24. With a single exception, his coins possess little interest.

Civitatibus. Asiae. Restitutis. *Tiberius sitting, with a sacrificial cup in his right hand, and in his left a sceptre.* Plate CCCCXXI. Fig. 25.

Tacitus and others relate, that, during the reign of this emperor, twelve cities in Asia Minor were almost entirely ruined by a dreadful earthquake. Tiberius advanced money to rebuild them; and to this circumstance the above coin and inscription allude.

Germanicus.

He was the son of Drusus, who was a younger brother of Tiberius. His noble character is well known from history. He was generally believed to have been taken off by poison administered at the instigation of Tiberius. By his wife Agrippina, the daughter of Agrippa, he had three sons, of whom the two eldest were disposed of by Tiberius; the youngest, Caius, succeeded to the empire.

Germanicus. Cæsar. *Germanicus on a triumphal car.*) (Signis. Receptis. Devictis. Germanis. S. C. *Germanicus holding in his left hand a staff with an eagle at the point of it.* Plate CCCCXXI. Fig. 26.

The obverse represents the triumph of Germanicus over the conquered Germans. The figure and inscription on the reverse allude to the recovery by Germanicus of the Roman eagles, which had been lost in the unfortunate defeat of Quinctilius Varus by the Germans under Arminius.

Caius Cæsar.

The son of Germanicus by Agrippina. He succeeded Tiberius in the empire, and reigned nearly four years. He obtained the nick-name of Caligula, because, while yet a boy, he used to wear the shoes which were worn by the soldiers.

His inscription was: C. Cæsar. Aug. Germanicus. P. M. &c.

Agrippina. Drusilla. Julia. S. C. *Three females, each holding in her hand a cornucopiæ*, Plate CCCCXXI. Fig. 27.

On this coin are represented the three sisters of Caligula, with their names inscribed.

R. CC. *Inscribed in the middle of small copper coins.* Plate CCCCXXI. Fig. 28.

In order to provide for the necessities of the state, Augustus imposed upon all goods brought to sale, a tax called *vectigal centesimæ*, or one *per cent.* When Tiberius had considerably increased the revenue by the conquest of the kingdom of Cappadocia, he reduced the tax to the *vectigal ducentesimæ*, or one half *per cent.* Caligula, however, abolished the tax altogether; and to commemorate this act, the senate caused the letters

RCC. (*i. e. Remissæ Ducentesimæ*) to be inscribed on the public coins.

Ti. Claudius.

He was a son of Drusus, and the younger brother of Germanicus. After the death of Caligula, he was proclaimed emperor by the soldiery.

His inscription was: Ti. Claud. Cæsar. Aug. Germ. &c.

Imperatore Recepto. *Inscribed over the gate of the camp of the guards.* Plate CCCCXXI. Fig. 29.

Praetorianis Receptis. *The emperor, dressed in the toga, holding out his hand to a soldier of the Prætorian guard, who holds a Roman eagle in his left hand.* Plate CCCCXXI. Fig. 30.

These two coins allude to the elevation of Claudius through the patronage of the soldiery.

Nero.

He was the son of Cn. Domitius Ahenobarbus, and of the younger Agrippina, daughter of Germanicus. He was adopted by Claudius, received the name of Claudius Nero, and succeeded to the imperial dignity.

His names appear thus upon coins: Nero. Claud. Cæsar. Aug. Germanicus. P. M. &c.

Congiarium I. Upon others: II. Datum Populo. *The emperor sitting upon an elevated stage, and dealing out presents to the citizens.* Plate CCCCXXI. Fig. 31.

The word *congiarium* is derived from *congius*, a certain measure for liquids, such as wine, oil, &c. The presents made to the people, upon certain occasions, having originally consisted of such articles, they were distinguished by the name of *congiaria*. Afterwards, indeed, they consisted also of other articles, such as corn, money, &c. but still retained the original name. They were marked on coins with the numbers I. II. III. &c. according as an emperor lived for a longer or shorter period, or was more or less liberal. In this respect, Nero was liberal even to extravagance. Instead of the word *congiarium*, the coins often bear Liberalitas Aug. and the addition of the numbers, with a female figure, holding in her right hand a *tessera*, or ticket entitling the bearer to certain articles.

Pace. P. R. Terra. Marique Parta. Janum Clusit. *The temple of Janus, with the gates shut.* Plate CCCCXXI. Fig. 32.

The practice of shutting the gates of the temple of Janus at Rome, during peace, is well known. It is only from coins we learn that such an event took place during the reign of Nero.

Pont. Max. Tr. Pot. &c. *Nero, dressed in a long robe, and playing on a lyre.* Plate CCCCXXI. Fig. 33.

History informs us of Nero's partiality for music. He carried it, indeed, so far, as to exhibit publicly, not only at Rome, but in Greece; where medals were also struck to commemorate the event, with the inscription ΝΕΡΩΝΙ. ΑΠΟΛΛΩΝΙ. and his portrait, as on the above Roman coin.

Portus. Ostiensis. Augusti. S. C. *The harbour of Ostia.* Plate CCCCXXI. Fig. 34.

The emperor Claudius rebuilt the harbour of Ostia, at the mouth of the Tiber, at great expense. It is probable that Nero completed the work, and that this coin was struck upon the occasion.

Servius Sulpicius Galba.

He was Proconsul in Spain, when he was called to supersede Nero in the government of the empire. He reigned eight months, and was assassinated by the Prætorian guards.

His inscription is—Servius Sulpicius Galba. Imp. Cæsar. Aug. or such like.

Hispania: *A female figure, holding in her right hand a bunch of corn-ears and a poppy, and in her left a round shield with two lances.* Plate CCCCXXI. Fig. 35.

Galba was partial to Spain and the Gallic provinces, because they were the first to declare for him against Nero. The attributes of Spain are the bunch of corn-ears, to denote its fertility; and the round shield and lances, the peculiar arms of the country.

M. Salvius Otho.

He ascended the throne, through the influence of the Prætorian guards, after the murder of Galba. He reigned only three months, having been defeated in a sanguinary battle by his rival Vitellius, upon which he laid violent hands on himself.

The inscription on his coins is—Imp. Otho. Cæsar. Aug. &c. On Roman coins his head is never surrounded with the laurel wreath, but covered with a sort of curly wig. Plate CCCCXXI. Fig. 36.

No reason has been assigned for the uncommon rarity of the brass coin of this emperor. There are, indeed, a good many of this metal, which, however, were not struck at Rome, but at Antioch in Syria, or at Alexandria in Egypt. All the brass Othos, which have the form of the Roman coinage, are forgeries. There are a good many of gold and silver, bearing his name and portrait, which were struck at Rome. Even the genuine coins of this emperor have nothing remarkable about them, excepting those which bear the inscription—Victoria Othonis.

A. Vitellius.

He reigned only eight months, when he was assassinated by the soldiers of Vespasian.

His inscription is—A. Vitellius. Imp. Germanicus.

XVVIR. Sacris Faciundis. *A Tripod, with a Dolphin lying upon it, and a Raven below.* Plate CCCCXXI. Fig. 37.

The principal duty of the *Quindecemviri sacris faciundis* was to consult the Sibylline books when Rome was threatened with any danger. The representation upon this coin, therefore, alludes to the soothsayer Apollo. We have the tripod upon which the priestess at Delphi sat when she delivered her oracles; the dolphin, because Apollo was chiefly worshipped at Delphi; and the raven, because that bird was supposed to have the faculty of foretelling future events. This subject seems to have been chosen by Vitellius, because, before he became emperor, he had been clothed with such a priestly office.

Flavius Vespasianus.

He was engaged in carrying on the war against the Jews, at the time when he was called to the empire by his legions, in opposition to Vitellius. He reigned nearly ten years, and built many splendid edifices; among others the capitoline temple, the temple of peace, and the amphitheatre.

His usual inscription is, Imp. Cæsar. Vespasianus. Aug.

Judæa. Capta, or Devicta, or De Judæis, S. C. *A female sitting under a palm-tree, and supporting her head with her hand.* Plate CCCCXXI. Fig. 38.

This alludes to the conquest of Judæa, and the capture of Jerusalem by Titus, the son of Vespasian, A. D. 70. The palm-tree is the symbol of Judæa, and is also found on some coins of Nerva.

The front of a splendid temple, decorated with statues. Jupiter sits in the middle, Minerva stands on his right hand, Juno on his left. Below, S. C. Plate CCCCXXI. Fig. 39.

During the confusion that occurred in the latter days of Vitellius, the temple of Jupiter Capitolinus was consumed by fire. Vespasian caused it to be rebuilt in the most splendid manner, chiefly at the expense of the Jews. The three deities abovementioned were placed in the temple exactly as they appear on the coin, Minerva occupying the most distinguished situation, on the right hand of Jupiter, in preference to Juno. For, after Jupiter, Minerva was most honoured at Rome. Thus Horace:

> *Proximos illi* (viz. Jupiter) *tamen occupavit*
> *Pallas honores.*

Thus, too, on the coins of Antoninus Pius, the birds sacred to these three deities are represented in precisely the same order: the eagle of Jupiter in the middle, the owl of Minerva on the right, and the peacock of Juno on the left.

Titus.

The eldest son and successor of Vespasian. He reigned two years. The Jewish war was terminated under his conduct. During his reign, that dreadful eruption of Mount Vesuvius first broke out, which overwhelmed the towns of Herculaneum and Pompeii.

His inscription is, Imp. Titus. Cæs. Vespasian, (or Divi Vespasiani Filius) Aug. P. M. &c.

S. C. *Titus sitting on a heap of arms.*) (*The amphitheatre.* Plate CCCCXXI. Fig. 40.

This coin represents the splendid amphitheatre, which was begun by Vespasian, and finished by Titus. It still remains a noble ruin, and is known by the name of the *Coliseum.*

Domitianus.

The second son of Vespasian, and successor of Titus. He reigned fifteen years, and was assassinated by his freedman Stephanus.

His inscription is, Imp. Cæs. Domit. Aug. Germ. P. M. &c.

Germanicus, or Germania. Capta. *A mourning female, as the symbol of Germany, seated on the long shield of the country, and beside her a broken lance.*

Domitian made war upon the Chatti, a German tribe dwelling on the Rhine, but soon returned home without effecting any thing of consequence. Upon this occasion he held a mock triumph, and assumed the title of Germanicus, to which he was ever afterwards particularly partial.

Cos. XIIII. Ludos Sæculares Fecit. *inscribed upon a pillar, beside which stands a candlestick, and a herald in his official habit.* Plate CCCCXXI. Fig. 41.

There are many coins of Domitian with this inscription, alluding to the celebration of the secular games in his fourteenth consulate. Augustus was the first of the emperors who celebrated these games, in the year of the city 737, as we know from coins. Upon that occasion, Horace composed his well-known secular ode, beginning

> *Phœbe, silvarumque potens Diana.*

In strict propriety, they should have been celebrated every hundred years; but this was not attended to; for we find they were celebrated sixty-three years afterwards (*An. U. C.* 800) under Claudius, and again, forty-one years after that, by Domitian; for which last we have the testimony of this coin, and of the historian Tacitus. We also find these games alluded to on coins of the emperors Severus and Philip.

Nerva.

He was advanced to the throne after the death of Domitian. He adopted Trajan as his son, and died in the sixteenth month of his reign.

His inscription is, Imp. Nerva. Cæs. Aug. P. M. &c.

Fisci. Judaici. Calumnia. Sublata. S. C. *A palm-tree.* Plate CCCCXXI. Fig. 42.

The Jews were liable to a tax of two drachmas for the maintenance of the temple at Jerusalem. After the conquest of Judæa by the Romans, the produce of this tax was employed for the support of the temple of Jupiter Capitolinus. Under Domitian, this tax was levied by the officers in a very oppressive manner; but by an ordinance of Nerva these abuses were rectified; and hence the inscription on this coin.

Vehiculatione. Italiæ. Remissa. S. C. *Two mules grazing; behind, a car.* Plate CCCCXXI. Fig. 43.

The *Vehiculatio* was a sort of villainage service, by which draught cattle and carriages were obliged to be kept on the highways, in Italy and the provinces, for the exigencies of the state. This was felt by the peasantry as an oppressive burden, which was accordingly alleviated by this humane emperor.

Trajan.

He died at Selinus, in Cilicia, in the twentieth year of his reign, having previously adopted Hadrian as his son.

His inscription at first was, Imp. Cæs. Nerva. Trajan. Aug. Germ. At a later period was added Dacicus, from his conquest of the Dacians; and Optimus, a title of honour which was conferred upon him by the senate. Hence we read upon the reverse of most of his coins, S. P. Q. R. Optimo. Principi. At last his titles were the following: Imp. Cæs. Ner. Trajano. Optimo. Aug. Ger. Dac. Parthico. The last epithet he took from his conquest of the Parthians.

Dacicus. Dacia. Capta. *A Dacian prisoner, with his hands bound behind his back, sitting upon three shields; behind him, two Dacian crooked sabres; before him, two darts.* Plate CCCCXXI. Fig. 44.

This alludes to the conquest of Dacia, which was made a Roman province. Hence Trajan took the title of *Dacicus.* Upon other coins of Trajan we read Dacia. Augusti. Provincia.

Danuvius. *A recumbent river-god, holding his right hand over a ship, and leaning with his left on a vessel, out of which water flows.* Plate CCCCXXII. Fig. 1.

This figure represents the river Danube, which it was necessary to pass in order to attack Dacia. Trajan caused an expensive stone bridge to be thrown over it, the direction of the architect Apollodorus of Damascus. This bridge, however, was demolished by his successor Hadrian, under the pretence that it afforded easy access to the barbarians to penetrate into the Roman empire. Some remains of this structure are still to be seen, near what is called the iron gate, between Servia and Wallachia.

VIA TRAJANA. *A female sitting on the ground, with her right hand on a wheel, and her left on a rock.* Plate CCCCXXII. Fig. 2.

Trajan, at great expense, made a road through the Pontine marshes, which from him was called the *Via Trajana.*

ALIMENTA ITALIÆ. *Trajan, dressed in the toga, stretching his hand over two children.* Plate CCCCXXII. Fig. 3.

This coin may be illustrated by a passage from Pliny's panegyric upon Trajan: *Paullo minus quinque millia ingenuorum fuerunt, quæ liberalitas principis nostri conquisivit, invenit, adscivit. Hi subsidium bellorum, ornamentum pacis, publicis sumptibus alantur, patriamque non ut patriam tantum, verum ut altricem amare condiscunt. Ex his castra, ex his tribus replebuntur,* &c.

FORUM. TRAJANI. *A splendid edifice, adorned with statues, pillars and ensigns of victory.* Plate CCCCXXII. Fig. 4.

BASILICA. ULPIA. *A splendid colonnade, decorated with statues.* Plate CCCCXXII. Fig. 5.

S. P. Q. R. OPTIMO PRINCIPI. *A spiral pillar, with the statue of the emperor at the top:* Plate CCCCXXII. Fig. 6.

These coins represent the magnificent buildings which Trajan erected at Rome. On the first we have the celebrated *Forum Trajanum.* The second exhibits the *Basilica,* a large building adorned with colonnades, intended for public assemblies. It was called *Ulpia* in honour of Trajan, who was of the Ulpian family. The third represents the splendid spiral pillar of white marble, which is still to be seen. It stood in the *Forum Trajani,* 140 feet high.

PARTHIA. CAPTA. *A pole for hanging armour between two Parthian prisoners.*

REX. PARTHIS. DATUS. S. C. *The emperor, on an exalted seat, placing the diadem on the newly appointed Parthian king, while a female, with a Parthian cap, kneels before him.* Plate CCCCXXII. Fig. 7.

ARMENIA. ET. MESOPOTAMIA. IN. POTESTATEM. P. R. REDACTAE. S. C. *Trajan, with the lance in his right hand, and in his left the sword,* (parazonium) *stands between two recumbent river-gods, who hold a ship in one hand, and with the other lean upon a water-urn. Between the emperor and one of these river-gods, a female, in the Armenian habit, is sitting on the ground, looking behind her.* Plate CCCCXXII. Fig. 8.

These coins allude to the conquest of Trajan, in the latter years of his reign, in Parthia, Armenia, and Mesopotamia. The two first relate to the subjugation of the Parthians. The third commemorates the conquest of Armenia and Mesopotamia. Armenia is distinguished by the female with the Armenian cap; Mesopotamia by the two river-gods, denoting the two rivers Euphrates and Tigris, between which that country is situated, and from which circumstance it derived its name.

HADRIANUS.

His usual inscription is only HADRIANUS. AUGUSTUS. He was the first of the emperors who allowed his beard to grow, because, it is said, he wished to be taken for a philosopher. The custom was continued by his successors, until Constantine the Great laid it aside.

I. AEGYPTOS. *A female seated on the ground, holding in her right hand the* sistrum, *and leaning with her left on a basket full of fruit: At her feet is the bird* Ibis. Plate CCCCXXII. Fig. 9.

AFRICA. *A female seated on the ground, her head adorned with the elephant's trunk, holding in her right hand a scorpion, or reaching towards a lion.*

DACIA. *A female sitting on a rock, holding in one hand a standard, in the other a crooked sabre.*

HISPANIA. *A female seated; in her right hand a sprig, and at her feet a rabbit.*

MAURITANIA. *A native holding a horse by the bridle.*

NILUS. *The bearded river-god lying on the ground. Several attributes are assigned him, such as the Sphinx, the Crocodile, the Hippopotamus, and, in particular, little dwarfish boys, who spring around and upon him.* Plate CCCCXXII. Fig 10. (And in like manner are represented: GERMANIA. NICOMEDIA, &c.

II. ADVENTUI, AUG. AFRICÆ. *The emperor dressed in the toga, and the female genius of Africa, adorned with the elephant's trunk, sacrifice upon an altar.* (And in like manner: ADVENTUI, AUG. ALEXANDRIÆ, or ASIÆ, or CILICIÆ, &c.) Plate CCCCXXII. Fig. 11.

III. RESTITUTORI. ACHAIÆ. *The emperor dressed in the toga gives his hand to the kneeling genius of Achaia; between them is a vessel with a palm-branch stretching out of it* (And in like manner: RESTITUTORI. AFRICÆ. ASIÆ. ARABIÆ. BITHYNIÆ. &c.) Plate CCCCXXII. Fig. 12.

IV. EXERCITUS. DACICUS. *The emperor on horseback harangues the legions.* (And in like manner: EXERCITUS. CAPPADOCICUS. BRITANNICUS. &c.) Plate CCCCXXII. Fig. 13.

The coins of this description are uncommonly beautiful and instructive. They comprehend almost all the Roman provinces, and confirm the historical fact, that Hadrian was employed, during the whole of his reign, in travelling through the extensive Roman territory. The first class contains the countries, towns, rivers, &c. which Hadrian visited; the second expresses the joy with which he was received; the third gives us an allegorical representation of the benefits he conferred on the oppressed provinces; and the fourth alludes to the legions distributed in the various districts. Here, too, we have the various attributes by which the provinces were distinguished. Egypt holds in her hand the *Sistrum,* a musical instrument peculiar to that country, and which was generally placed in the hand of the goddess Isis. Egypt is also distinguished by the basket of fruit, denoting the fertility of the land, and by the bird called Ibis, which was worshipped there. Africa is distinguished by the animals peculiar to tropical climates: such as the elephant, the scorpion, the lion. Dacia is represented sitting upon a rock, to denote the mountainous nature of the country. The crooked sabre was also peculiar to the Dacians. Spain has her rabbit, an animal which anciently abounded in that country. Mauritania (the modern Barbary) is distinguished by the horse, an animal for which it is still famous. The river Nile was worshipped as a god in Egypt, in consequence of its annual overflowings, which tended to promote the singular fertility of that country. His attributes are the sphinx, the crocodile, and the hippopotamus. But the most amusing representation of the Nile consists of the sixteen sportive dwarfs, denoting the sixteen ells which it was necessary the river should rise above its usual surface in order to insure an abundant harvest. On this subject Pliny says: *Justum incrementum est cubitorum XVI. In XII. cubitis Aegyptus famem sentit, in XIII. estiamnum esurit, XIV. cubita hilaritatem adferunt, XV. securitatem, XVI. delicias.* To mark this last increase, we frequently find upon Egyptian coins the Greek number ις (16.) indicating that, in that year, the Nile attained that height.

P. M. Tr. P. Cos. III. *A temple, in which Hercules appears standing between two females, each of whom endeavours to allure him to herself.* Plate CCCCXXII. Fig. 14.

This piece represents the well known beautiful moral allegory—*the Choice of Hercules*, by Prodicus. In relation to Hadrian, it seems to denote his activity and self-denial in undertaking such troublesome journies, in order to promote the welfare of the provinces.

Locupletatori. Orbis. Terrarum. *The emperor seated on an elevated stage, before him the figure of Liberality, who pours out treasures from a* Cornucopiæ *upon two citizens standing below.* Plate CCCCXXII. Fig. 15.

This was a title conferred upon Hadrian, in consequence of his great liberality.

Saeculum Aureum. P. M. Tr. P. Cos. III. *The figure of a man, holding in one hand a phœnix, and in the other a circle, which completely surrounds him.* Plate CCCCXXII. Fig. 16.

From the panegyrical inscription upon this coin, it would appear that the reign of Hadrian was considered as a golden age. The phœnix was anciently the symbol of a long continued period; the circle represents the zodiac, as the measure of time by the course of the sun.

Antoninus Pius.

He was adopted by Hadrian, and succeeded him in the government. In consequence of his philanthropic disposition, he acquired the title of *Pius.* He reigned twenty-three years.

His usual inscription was: Imp. Caes. T. Aelius. Hadrianus. Antoninus. Pius. Aug. The names *Aelius Hadrianus* he derived from Hadrian by adoption.

Asia. *A female figure with a crown in her right hand, an anchor in her left, and at her feet a ship.* Plate CCCCXXII. Fig. 17.

Cappadocia. *A similar figure, holding in her right hand a vessel, in her left a standard, and at her feet the mountain Argæus.* Plate CCCCXXII. Fig. 18.

Parthia. *A Parthian, holding in his right hand a crown, in his left a bow and quiver.*

Phoenice. *A female figure, holding a vessel in her right hand; behind is a palm-tree.* (And in like manner: Africa. Dacia. Scythia. Sicilia. &c.)

On all coins of this description, the genius of a province is exhibited in the act of presenting a crown, or a small chest. Among the ancient Greeks, it was customary to present to princes and great men golden crowns, with a view to secure their friendship, or to avert their anger. This practice found a favourable reception among the Romans. Historians make frequent mention of golden crowns, presented by towns and countries to Roman generals, when they entered their territory. These gifts, on the part of the provinces, became very frequent under the emperors. Although at first voluntary, they afterwards became compulsory, and differed from real tribute only in the name. The gist of not always consist of a real crown, but often of gold coin or bullion, from which circumstance it was called *aurum coronarium*, or *crown-gold.*

When Antoninus assumed the government, the deputies from the provinces immediately appeared with their golden crowns. The names of the various provinces appear on the above coins, and they are usually represented by female figures, in the act of presenting either a real crown, or a vessel containing the crown-gold. History informs us, that this philanthropic emperor remitted the gift entirely as to Italy, and reduced it to one half as to the provinces.

With respect to the attributes of the provinces, *Asia* has a ship and an anchor, because the Romans could only get to it by sea. *Cappadocia* has the mountain Argæus, which was worshipped by the inhabitants as a god. *Parthia* has the bow and quiver, because the Parthians were esteemed the best archers. *Phœnicia* has a palm-tree, from which that country derived its name.

Rex. Armeniis. Datus. *Antoninus dressed in the toga, placing the crown on the head of the Armenian king.* Plate CCCCXXII. Fig. 19.

Rex. Quadis. Datus. *Antoninus presenting his hand to the new king of the Quadi.* Plate CCCCXXII. Fig. 20.

These pieces are of the same description with the coins of Trajan formerly noticed. It is only from these monuments, we may observe, that we learn the facts which they commemorate.

Faustina Senior.

She was the wife of Antoninus Pius, but died in the third year of his reign. Antoninus made a goddess of her, built her a temple, and caused a number of the most beautiful medals to be struck in honour of her.

Diva. Aug. Faustina. Head of Faustina.) (Pvellae. Faustinianae. *Antoninus, sitting upon a stage, stretching towards a child, presented to him by a figure below.* Plate CCCCXXII. Fig. 21.

To explain the reverse, we must observe, that Antoninus, following the noble example of Trajan, formerly alluded to, founded an institution for the education of poor girls, who were called *Puellæ Faustinianæ.*

M. Aurelius Antoninus.

He was adopted by Antoninus Pius, received the title of Cæsar, and succeeded to the empire. He associated L. Verus with himself in the government, so that there were then, for the first time, two Augusti. He died at Vindobona in Pannonia—the modern Vienna—in the twentieth year of his reign.

His inscription, as Cæsar, was: Aurelius. Cæsar. Augusti. Pii. Filius.; as emperor: Imp. Cæs. M. Aurel. Antoninus. Aug. Afterwards he assumed other titles from his conquests; such as: Armeniacus, Parthicus Maximus, and on some of his rarest coins, Medicus, from his conquest of the Medes; and finally, Germanicus. Sarmaticus.

Concordiæ. Augustor. Tr. P. XV. Cos. III. *The two emperors, Aurelius and Verus, present their hands to each other.* Plate CCCCXXII. Fig. 22.

De Germanis. or De Sarmatis. *A heap of German arms, or a trophy between two Sarmatian prisoners.* Plate CCCCXXII. Figs. 23, 24.

These heaps of arms denote the victories obtained over the Germans and Sarmatians, by which Aurelius procured the titles *Germanicus* and *Sarmaticus.*

Faustina Junior.

The daughter of Antoninus Pius, and wife of M. Aurelius; a woman of a most abandoned character. Nevertheless she was deified after her death.

Faustina Augusta. *Head of Faustina.*) (Fortunae. Muliebri. *Fortune, in a sitting posture, holding in her right hand a rudder, and in her left a cornucopiæ.* Plate CCCCXXII. Fig. 25.

Fortune was a favourite divinity at Rome, where she had many temples, and was worshipped, indeed, both as a male and a female, under various appellations.

Commodus.

The son of M. Aurelius, and of the younger Faustina.

His inscription is very variable. He sometimes took the *prænomen* of *Lucius*, sometimes of *Marcus*. His other names were: *Aelius Aurelius Antoninus Commodus Pius Felix*, and also *Britannicus*, from the conquered Britons.

Colonia Lucia Antoniniana, Commodiana. P. M. Tr. P. &c. *Commodus, veiled, conducts a plough yoked with oxen.* Plate CCCCXXII. Fig. 26.

History informs us, that Commodus, in one of his wild freaks, resolved to change the name of the imperial city, and to convert it into a colony, under the designation of *Colonia Commodiana.* The truth of this foolish idea is confirmed by the above coin. The reverse gives us a representation of the manner of founding a Roman colony. Its limits were marked out by a furrow made by a plough drawn by a bullock and a cow. This act was accompanied with religious ceremonies; for he who conducted the plough, was always veiled after the manner of the priests.

Herculi Romano Augusto. *Hercules holding his right hand over a trophy, and in his left the club and lion's skin.* Upon other coins, instead of the figure of Hercules, we find only his usual attributes. Plate CCCCXXII. Fig. 27.

Herculi Romæ Conditori. Cos. VII. P. P. *Hercules holding the plough. On the obverse is the head of Commodus covered with the lion's skin.* Plate CCCCXXII. Fig. 28.

Commodus possessed great bodily strength, and deified himself under the name of Hercules. He laid aside the laurel wreath, which had hitherto adorned the heads of the emperors, and assumed the lion's skin. In this form he was frequently represented in statues and on coins.

P. Helvius Pertinax.

He was a man of low extraction, but was raised to the imperial dignity after the murder of Commodus. He was himself assassinated, however, by the prætorian guards, in the third month of his reign.

His inscription was: Imp. Cæs. P. Helv. Pertinax. Aug.

Jano Conservatori. *Janus holding in his right hand a lance.*

Pertinax probably chose Janus for his tutelary god, in consequence of his having been appointed emperor in the month of January.

Menti. Laudandae. *A female, with a crown in her right hand, and in her left a lance.* Plate CCCCXXII. Fig. 29.

Under the word *Mens*, was understood the disposition, which is capable of receiving a good or a bad direction. The *Bona Mens* had actually a temple at Rome, and was worshipped as a goddess. As the *mala mens* seemed to prevail during the whole reign of Commodus, Pertinax wished to restore the *mens bona*, or, which is the same thing, the *mens laudanda*, to her former honours.

After the violent death of Pertinax, Didius Julianus bought the empire from the Prætorian guards. Several competitors, however, started up, in the persons of Severus in Pannonia, Clodius Albinus in Gaul, and Pescennius Niger in the East; all of whom assumed the title of emperor. Severus advanced with his legions to Rome, and prevailed upon the senate to deliver over the cowardly Julian to execution. He afterwards gradually overcame Albinus and Pescennius, and again united the empire under one head.

There is nothing remarkable in the coins of Julian and Albinus. Those of Pescennius are much valued on account of their rarity. Most of them, however, like those of Otho, are forgeries. On his genuine *denarii*, he generally has the title of *Justus*, and the inscription: Imp. Cæs. Pesc. Niger. Just. Aug. The figures on the reverse are generally of a mythological description. One of the most rare coins of Pescennius is that in the imperial cabinet at Vienna, on which there is *a basket filled with corn-ears, grapes, and other fruits*, with the inscription: Felicitas Temporum. Plate CCCCXXII. Fig. 30.

L. Septimius Severus.

He was born in Africa, and died during the war in Britain, in the 19th year of his reign.

His inscription was, L. Septimius Severus Aug. sometimes with the addition of Pertinax. From his conquests he assumed the title of Parthicus Maximus, and also of Britannicus.

The bust of Severus.) (Felicitas. Saeculi. *The head of a female between two youthful male heads.* Plate CCCCXXII. Fig. 31.

The obverse of this coin exhibits the portrait of Severus; the reverse that of his wife Julia Domna, and her two sons, Caracalla and Geta, who both succeeded to the imperial dignity. Some of the coins of this description have also the inscription, Æternit. Imperii.

Divi. Marci Pii. Filius. P. M. Tr. P. III. Cos. II. P. P. S. C. *Severus, holding the globe and the goddess of victory in his right hand, and a lance in his left, is crowned by Courage* (Virtus) *who carries a club.* Plate CCCCXXII. Fig. 32.

Severus publicly held himself out as the son of M. Aurelius, although there was no relationship whatever between him and the Antonines. On public monuments, however, we find him designated as the *son of M. Aurelius, the brother of Commodus, the grandson of Antoninus Pius*, &c. He also gave his son Bassianus the name of Antoninus. All this, no doubt, was done from policy, for the memory of the Antonines was held sacred at Rome.

M. Aur. Antoninus Caracalla.

He was the eldest son of Severus and Julia Domna. When scarcely ten years old, Severus gave him the title of Augustus, and assumed him as co-regent. His father intended that the two brothers, Caracalla and Geta, should be joint emperors; but Caracalla murdered his brother, and reigned six years alone, when he was assassinated in Mesopotamia, at the instigation of Macrinus.

His inscription is, M. Aurelius. Antoninus. Pius. Felix. Aug. The name Caracalla never appears on public monuments. From his father he derived the titles of *Parthicus Maximus*, and he ultimately assumed also that of *Germanicus*.

P. M. Tr. P. XVII. Cos. IIII. P. P. *Æsculapius, holding in his right hand the serpent rod; beside him stands the little Telesphorus, and at his feet lies the globe.* Plate CCCCXXII. Fig. 33.

Apollo holding a branch in his right hand, and leaning with his left on the lyre, which lies upon a tripod. Plate CCCCXXII. Fig. 34.

Hercules holding a branch in his right hand, and in his left the club and lion's skin. Plate CCCCXXII. Fig. 35.

These coins were struck during the latter years of his reign, and allude to the bad state of his health. Hence we find upon them the figures of such deities as were supposed to preside over medicine and health, viz. Æsculapius, Apollo, Hercules, and Telesphorus.

Divo. Antonino. Magno. *Head of Caracalla.*) (*Consecratio. An eagle.* Plate CCCCXXII. Fig. 36.

After his death, Caracalla, notwithstanding the baseness of his character, was placed among the gods by a decree of the senate. To this circumstance the above coin alludes.

CLASS II.

OF THE COINS STRUCK OUT OF ROME.

The coins belonging to this class are equally numerous, and, in many respects, still more interesting, than those of the former. Their number, indeed, must be exceedingly great, as almost every Greek town, however insignificant, had its own coinage; and the same may be said of foreign kings. It is certain, that the mere names of the nations, towns, kings, &c. whose coins are still extant, amount to 2000. Their excellence consists partly in the extraordinary beauty of those which were executed during the happiest times of art, and partly in the interesting materials they present to the study of the philosopher. As the Roman class is now nearly exhausted, it is chiefly to this latter class that the attention of the skilful collector is at present directed.

The coins of this class are subdivided into, I. The coins of nations and cities; and II. the coins of kings and princes under various titles.

PART I.

Coins of Nations and Cities.

These are either of the description called Autonomes, that is, coins on which neither the portrait nor the name of an emperor or king appears; or, *imperial coins of cities*, such as have the portrait and the name of a Roman emperor upon them; or, lastly, *colonial coins*.

1. *Autonomic Coins.*

Macedonia.

Head of Diana, encircled by a wreath of Macedonian shields.) (ΜΑΚΕΔΟΝΩΝ. ΠΡΩΤΗΣ. *The club of Hercules in the middle of an oaken wreath.* Plate CCCCXXII. Fig. 37.

After the conquest of Macedonia by the Roman general Æmilius Paulus, he divided the country into four parts. The inscription on the reverse of the above coin shows that it belonged to the first division. There are a great number now extant of the silver coins of this division; while those of the second and fourth are rare; and of the third none have yet been found. The club, on the reverse, alludes to Hercules, who was particularly honoured in this country, as its kings were supposed to be descended from him.

Beotia.

A shield) (ΒΟΙωτων. *A vase; in the field a bunch of grapes and a club.* Plate CCCCXXII. Fig. 38.

The shield, with the circular incision on both sides, was peculiar to the Beotians. The grapes and club allude to Bacchus and Hercules, who were both born at Thebes, the capital of Beotia.

Tarentum Calabriae.

ΤΑΡΑΣ. *A youth riding upon a dolphin.*) (*Two youths on horseback.* Plate CCCCXXII. Fig. 39.

ΤΑΡΑΣ is the Greek name of Tarentum, once a wealthy and powerful city in Calabria. The youth borne on the dolphin is Taras, a son of Neptune, from whom the city received its name. The reverse alludes to the Tarentine cavalry, which was famous. The wealth of this city appears from the great number of its beautiful gold and silver coins.

Syracusæ Siciliæ.

ΑΡΕΘΟΣΑ. *A beautiful female head, with the hair sticking out on all sides.*) (ΣΥΡΑΚΟΣΙΩΝ. *A youth in a chariot and four, in full career, crowned by a winged goddess of victory.* Plate CCCCXXII. Fig. 40.

Syracuse is still the Peru of the collectors of coins. No Greek city presents us with so many gold and silver pieces, and of such weight. Its coins, too, excel all antiquity in the taste and beauty of their workmanship. The obverse of this coin represents the celebrated fountain of Arethusa, situated near the town and the sea; a divinity in the eyes of the Syracusans, and a favourite theme with many an inspired poet. The figure on the reverse, which always appears upon the Sicilian coins, contains an allegorical representation of their victories. The inscription, it will be observed, is in the Doric dialect.

Athenæ Atticæ.

Head of Minerva.) (ΑΘΕ. ΝΕΣΤΩΡ. ΜΝΑΣΕΑΣ. *An owl standing upon a vase; and a stag; round the edge a wreath of olive.* Plate CCCCXXII. Fig. 41.

This was the common silver coin of Athens. Minerva was the tutelary goddess of the Athenians; hence they placed her favourite bird, the owl, upon their coins. Considered as specimens of art, they are but indifferent. On the reverse, we generally find the names of various magistrates; as, upon the present, those of Nestor and Mnaseas.

Lacedæmon Laconiæ.

Head of Hercules crowned with laurel.) (ΛΑ κεδαιμο-

νιων ΓΕΙ ΙΠΠȣ. *A vase between the caps of the* Dioscuri. Plate CCCCXXII. Fig. 42.

This is a silver coin of Lacedæmon. Their great lawgiver Lycurgus, indeed, allowed only iron money; and we have no very ancient silver or brass coins of this people. But afterwards, when they departed from the laws and institutions of Lycurgus, they coined money of various metals. The obverse of this coin exhibits the head of Hercules, from whom their kings were descended. The caps on the reverse belong to the *Dioscuri*, Castor and Pollux, who were particularly reverenced at Sparta, being born of Leda, a Spartan.

SMYRNA IONIÆ.

ΟΜΠΡΟϹ. *Homer seated, holding in his hand a roll of writing.*) (ϹΜΥΡΝΑΙΩΝ *inscribed within an oaken wreath.* Plate CCCCXXII. Fig. 43.

This copper coin belongs to Smyrna, a considerable town in Ionia, and alludes to its pretensions to the birthplace of Homer. A temple was erected to him in this town, and medals were struck in honour of him, which, from bearing his portrait, were called the *Homeric*.

CYRENE CYRENAÏCÆ.

ΚΥΡΑ. *A bearded portrait, with a ram's horn.*) (*The plant Laserpicium.* Plate CCCCXXII. Fig. 44.

This coin was struck at Cyrene, (*doricè* Cyrane,) a town founded by a colony of Spartans on the African coast. The coins struck here, of gold and silver, are distinguished for the great beauty of their execution. On the obverse, we find the head of Jupiter Ammon, with his attribute, the ram's horn. His celebrated temple was situated at no great distance from Cyrene. On the reverse is the famous plant *Laserpicium*, (the σιλφιον of the Greeks,) of the virtues of which the ancients had a great idea. It was much cultivated here; and hence it was employed by the Cyrenæans as the national symbol.

2. *Imperial Coins of Cities.*

The coins of this description are very numerous; but they become rare from the time of Gallienus. The following is a single specimen.

EPHESUS IONIÆ.

Α. ΑΥΡ ΚΟΜΟΔΟϹ. ΚΑΙϹΑΡ. *The unadorned head of the young Commodus.*) (ΑΡΤΕΜΙϹ. ΕΦΕϹΙΟΝ. *The Diana of Ephesus between two stags; above are the sun and moon.*

This coin belongs to Ephesus, a well known town in Ionia. On the obverse, Commodus appears without the laurel wreath, as he had not yet obtained the title of Augustus. On the reverse is the Diana of the Ephesians, whose magnificent temple is well known.

3. *Colonial Coins.*

The coins of this description were struck in those towns which were converted into Roman colonies; after which the inscriptions were generally in Latin, even although the Greek were the native dialect. The letters COL. or ΚΟΛ. were always prefixed to the name of the town. There are in this class also some autonomic coins; but these are not numerous. The following is a specimen of this class:

VIMINACIUM MŒSIÆ.

IMP. GORDIANUS. PIUS. FEL. AUG. *Head of the emperor Gordianus, with a radiating crown.*) (P. M. S. COL VIM. *A female genius, holding in her right hand a standard, with the number* VII. *inscribed on it, in her left another, with the number* IIII.; *at her feet are, on the right a bullock, and on the left a lion, below* AN IIII. Plate CCCCXXII. Fig. 45.

The inscription on the reverse is completed thus: *Provinciæ Mœsiæ Superioris* COLONIA VIMINACIUM. The colony of Viminacium was situated in upper Mœsia on the river Ister. The privileges of a Roman colony were conferred upon it by the emperor Gordian, who caused it to be occupied by two legions, the seventh and the fourth. Hence the numbers upon the reverse, and the bullock and lion, which were the respective symbols of these two legions. The number at the bottom indicates that this coin was struck in the fourth year of the colony. A great number of the coins of this colony are found in the Austrian territories, especially in Hungary.

Of the same description are the coins with the inscription PROVINCIA DAOICA.

PART II.

COINS OF KINGS AND PRINCES.

We have very few coins belonging to those monarchies which existed before the time of Alexander the Great. The greatest part are of those kingdoms which fell to the lot of Alexander's generals. Of these the most remarkable are *Macedonia*, *Egypt*, and particularly *Syria*. We shall notice a few specimens of the numerous collection of coins of this description.

GELO R. SYRACUSARUM.

Head of king Gelo encircled with the diadem.) (ΒΑ. ΓΕΛΩΝΟΣ ΣΥΡΑΚΟΣΙΟΙ. *An eagle standing upon a thunderbolt.* Plate CCCCXXII. Fig. 46.

This coin was struck in honour of Gelo, king of Syracuse, whose valour and other virtues procured for him the attachment of his subjects during his life, and their reverence for his memory long after his death. His reign occurred nearly 500 years before the Christian æra.

PHILIPPUS II. R MACEDONIÆ.

Head of Apollo.) (ΦΙΛΙΠΠΟΥ. *A man in a chariot and pair in full career; a vase between the feet of the horses.* Plate CCCCXXII. Fig. 47.

Such was the gold coin which Philip II. of Macedon caused to be struck, in great quantities, after his conquest of the Thracian gold mines, and which was every where known by his name. The reverse alludes to the victories which Philip had obtained on the Olympic course.

ALEXANDER MAGNUS.

Head of Minerva.) (ΒΑΣΙΛΕΩΣ. ΑΛΕΞΑΝΔΡΟΥ. *The goddess of victory, holding in her right hand a wreath, and in her left a trident.* Plate CCCCXXIII. Fig. 1.

Head of Hercules with the lion's skin.) (ΑΛΕΞΑΝΔΡΟΥ. *Jupiter seated, holding in his right hand an eagle, in his left a lance; in the field a lyre, and near it* ΚΟΛΟ. Plate CCCCXXIII. Fig. 2.

In the first of these pieces we have the common gold coin; in the second, the common silver coin of Alexander the Great. On the latter, we find the letters ΚΟΛΟ. denoting Colophon, a considerable town of Ionia, where the coin was struck. The lyre is its symbol, because Apollo was principally worshipped there.

Mithridates VI. R. Ponti.

Head of the king with the diadem.) (ΒΑΣΙΛΕΩΣ ΜΙΘΡΑΔΑΤΟΥ ΕΥΠΑΤΟΡΟΣ. *Pegasus grazing; in the field, the year* ΘΣ (209.) *An ivy wreath goes round the edge.* Plate CCCCXXIII. Fig. 3.

The obverse has the portrait of the celebrated king of Pontus, Mithridates Eupator. The figure of Pegasus leads to the supposition that coins like this were struck at Amisus, one of the principal towns of Pontus, of which this figure was the symbol. The number ΘΣ denotes the 209th year of the Pontic æra. The ivy wreath is placed here, because this king was flattered with the appellation of Bacchus, who generally wore a garland of ivy.

Antiochus R. Syriæ.

King's head with the diadem.) (ΒΑΣΙΛΕΩΣ. ΑΝΤΙΟΧΟΥ. *Apollo, holding in his right hand an arrow, and in his left a bow, sitting on a covered tripod.* Plate CCCCXXIII. Fig. 4.

On the obverse is the head of Antiochus. The figure on the reverse is generally found on the coins of the first Syrian kings, and represents Apollo the soothsayer.

Ptolemæus I. R. Ægypti.

King's head with the diadem.) (ΠΤΟΛΕΜΑΙΟΥ ΣΩΤΗΡΟΣ. *An eagle standing upon a thunderbolt; in the field the year* ΛΓ. (33.) Plate CCCCXXIII. Fig. 5.

This coin belongs to Ptolemy, the son of Lagus, one of the most distinguished of Alexander's generals, and the founder of the Egyptian monarchy. The number ΛΓ. denotes the 33d year of his reign.

There are other coins of princes, with various titles. Herod the Great, before the Romans raised him to the royal dignity, had on his coins the inscription, ΗΡΩΔΗϹ. ΕΘΝΑΡΧΟϹ. *i. e. ruler of the people.* His son, Herodes Antipas, called himself *Tetrarch*, ΗΡΩΔΟΥ ΤΕΤΡΑΡΧΟΥ. The titles of *Toparch* and *Dynast* occur less frequently.

MODERN NUMISMATOLOGY.

We propose to discuss this branch of our subject with great brevity, as it does not possess nearly so much interest as that which we have just been considering.

With regard to the Italian coinage, besides some coins of the Gothic princes, the exarchs of Ravenna struck money with the inscription, Felix Ravenna, &c. The papal coinage originated with Hadrian I. consisting of silver pennies, with the pope's name on one side, and Scos Petrus on the other. There are no coins from 975 to 1099, excepting of Leo IX. There are groats of Clement V. with his portrait; but the side-head begins with Sixtus V. in 1470. Gold was first coined by John XXII. in 1316. The coins of Alexander VI. Julius II. and Leo X. are remarkable for their elegance and beauty. The coinage of Milan began with Charlemagne; that of Naples in 840 and 880, with Duke Sergius and Bishop Athanasius. Gold was first coined at Venice in 1280, and copper in 1471; but the silver groats are as old as 1192. Silver was coined at Florence in the 12th century, or before. In 1252, the first gold coins struck in Europe, after the eighth century, made their appearance here, and were called *florins*, from the flower of the lily upon them,—an emblem which was afterwards adopted by France.

The most early series of Spanish coins consists almost entirely of *trientes*, finely executed. On one side they have the head of the king, with his name, and on the other a cross, with the name of the town, commonly in Bœtica, or the southern part of Spain. The Moresque coins of Spain have nothing but insipid inscriptions on both sides. The inscriptions on the ancient Spanish coins are in the Cufic or old Arabic characters.

It would lead us into a wide, and by no means a very interesting field of research, were we to attempt a description of the coins of Germany, and the northern kingdoms of Europe; we shall therefore conclude with an account of the coins of France, England, and Scotland.

The French coins during the race of Clovis, from 490 to 751, are chiefly gold *trientes*, with some *solidi* and *semisses*. The former are of good execution, having the heads of the kings on the obverse, and a cross, with the name of the town where they were struck, on the reverse. The coins of the second race, from Pepin, in 751, to Hugh Capet, in 987, are of inferior workmanship. Those of Charlemagne are generally rude; those of Louis le Debonnaire are better done. With regard to the third race, beginning with Hugh Capet in 987, it may be observed, that the coinage did not begin to improve until the introduction of the *grosse*, or groat, under St. Louis, in 1226. Many base coins were circulated after the conquest of France by the English; and copper was first introduced into the French coinage in the time of Henry III. in 1574. The *ecu à la couronne*, or gold crown, was struck by Charles VI. in 1384, and by Ann of Bretagne in 1498; the *teston*, with the king's head, by Louis XII.; the *Henri*, with Gaul sitting in armour, and a Victory in her hand, by Henry II. There are many coins of Cardinal Bourbon, in 1589; and in 1642, Louis XIV. assumed the title of *Cataloniæ Princeps*. The first *Louis d'or* appeared in 1640. The medals of Louis XIV. are also remarkable.

The coins of the Heptarchy were of two sorts; the *skeatta*, or penny of silver, and the *styca* of copper. Few of the pennies appear till after the year 700; though some are found as old as 560, which bear the name of Ethelbert I. king of Kent. At first they had only rude figures of serpents, but in latter times legends were also added. The *styca* was coined only in Northumberland, being a very small piece, about the value of half a farthing. The coins of the monarchs in England form almost a complete series from the time of Egbert, in 832, to that of Edgar, who reigned in 959: the only monarch of whom there are no coins is Ethelbald, who reigned in 857. Most of these coins have rude portraits; but the reverses are sometimes curious and interesting. There are also ecclesiastical coins of the archbishops of Canterbury; Walfred in 804, Coolnoth in 830, and Plegmund in 889.

The silver penny, which had commenced during the heptarchy, continued to be the common coin after the kingdom had been united under one head; and it extends in a continued series from Egbert almost to the present time. The only kings wanting are, Edmund Ironside, Richard I. and John. The weight of the penny was originally 22½ grains: but it was gradually diminished, until, in the reign of Elizabeth, it was only $7\frac{1}{31}$. Silver halfpennies and farthings were first struck by Edward I. in 1280. The former continued to the time of the commonwealth ; but the latter ceased with Edward VI. The groat was introduced by Edward III. in 1354 ; and the half groat, or two-pence, is of the same date. Shillings (from the German *schilling*) were first coined by Henry VII. in 1503. They were originally called *testoons*, from the *teste* or head of the king upon them. The crown, which had formerly appeared only in gold, was first coined in its present form by Henry VIII.; the half-crown, sixpence, and threepence, by Edward VI. In 1558, Queen Elizabeth coined three-halfpenny, and, in 1561, three-farthing pieces ; but these were discontiued in 1582.

A gold penny was coined by Henry III. in 1257 ; but the series of gold coinage in England properly commences with Edward III., who, in 1344, first struck florins, in imitation of those of Italy. These coins, when first issued, bore the value of only six shillings, though now intrinsically worth 19 shillings. The half and quarter florin were struck at the same time, but the latter only has been found. The florin gave way to the noble, of the value of 6s. 8d., which had its name from the nobility of the metal ; the gold of which it was coined being of the finest kind. It was sometimes called *rose noble*, from both sides being impaled in an undulating circle. There were also half and quarter nobles. In 1465, the gold coinage was augmented by the angels of Edward IV., so called from being stamped with the figure of Michael and the dragon. The angelets, of the value of 3s. 4d. were afterwards substituted in their place. In 1527, Henry VIII. added to the coined gold, crowns and half-crowns, at their present value ; *sovereigns*, at 22s. 6d. ; ryals, at 11s. 3d.; angels, at 7s. 6d. ; and nobles at their old value. In 1546, he coined sovereigns at 20s. and half-sovereigns in proportion. All the coinage of this monarch, however, is much debased ; and it was with much difficulty that Edward VI. brought it back to its former standard. Besides sovereigns, James I. coined *rose-ryals*, of 30s. value, *spur-ryals*, of 15s, angels of 10s., and angelets of 5s. The sovereign continued until it was superseded by the guinea, so called from being coined of Guinea gold, which was at first intended to go for 20s., though, by universal but tacit consent, they have always passed for 21s. Half-guineas, double-guineas, and five-guinea pieces were also coined ; as were quarter-guineas by George I. and III. ; but these last were soon stopt on account of the inconvenience of their small size. A few pieces of 7s. have likewise been coined. The value of the guinea gradually increased until it was as high as 30s. ; but after the recoinage in 1697 and 1698, it fell by degrees, and in 1717 it was at its old standard of 21s. The sovereign of 20s. has again been issued by his present majesty.

There is nothing very remarkable in the copper coinage of England, which frequently consisted, in a great measure, of private tokens. The farthings of Queen Anne, however, form an exception. These are of exquisite workmanship, and superior to most ancient or modern copper coins ; the one having on the reverse Peace in a car, Pax missa per orbem, is the most esteemed ; and next to it the Britannia under a portal.

With regard to the coinage of Scotland, it is believed that there exist silver pennies of Alexander I. who reigned in 1107 ; and there certainly are some of Alexander II. in 1214, as also of David in 1124. There are many coins of William I. in 1165 ; and a large hoard of his pennies was found at Inverness in 1780. The money of Scotland was of the same value with that of England, until the vast drain occasioned by the enormous ransom of David II., after which its size was reduced ; and its value continued to diminish to such a degree, that, in 1600, it passed only for a twelfth part of the English money, and remained at that low ebb until the union of the two kingdoms.

The only silver coin was the penny, until the year 1293, when Alexander III. coined also half-pence ; and there are silver farthings of Robert I. and David II. The groat and half-groat were also introduced by the latter, which completed the set of Scottish silver. These all ceased to be coined in the time of Queen Mary ; when shillings were first coined, with the bust of the queen on one side, and the arms of France and Scotland on the other. The silver crown, of the value of 30s. Scots, was first coined in 1565 ; smaller pieces of 20s. and 10s. were likewise struck, and marks of silver, worth 3s. 4d. English. These coins have the mark XXX. XX. X. upon them, to denote their value. The motto Nemo me impune lacesset first appears on Scottish coins in 1578. The crown of an ounce weight gradually increased in nominal value, until, in 1601, the mark was LX. In the time of Charles I. half marks, 40 and 20 penny pieces, were coined. In 1665, the Scottish dollars first appeared, in value 56s. Scots, with the half and quarter of proportional value. In 1686, James VII. coined 60s. 40s. 20s. 10s. and 5s. pieces ; but only those of 40s. and 10s. are known. At the union of the kingdoms, all the Scottish coins were called in and recoined at Edinburgh, with the mark E under the bust. In general, the Scottish silver coins are equal, if not superior, in execution, to the English.

Gold was first issued in Scotland by Robert II. The pieces were at first called St. Andrews, from the figure of that tutelar saint upon the cross. The lion was another name for the largest gold coins, from the arms of the kingdom upon it. Then comes the unicorn, under James III. ; which was followed by the bonnet-pieces of James V. ; which last are of admirable workmanship. The last gold coined in Scotland consisted of the pistole and half pistole, of twelve and six pounds Scots, which have the sun under the head.

The Scottish copper coinage is of an earlier date than that of England. It was preceded by money of billon, called black money, consisting of copper washed with silver. The true copper coinage began in the time of James VI. The *bodle*, so called from Bothwell the mint-master, was worth two pennies Scots. The *baw-bee* (*bas piece*) was also coined, corresponding with the English halfpenny. Some pieces called Atkinsons were also coined by James VI. in 1582, which went for a third more than the value of the baw-bee. Besides these, there were the hardie and the plack, the former worth three, the latter four pennies Scots. The Scottish coins of Charles I. are very rare.

Besides the regular coinage, there are various Scottish medals deserving of notice. The first modern medals of gold were those of David II. struck between the years 1330 and 1370, of which only two are known to exist. In 1487, there is a medal of James III. sent to the shrine of St. Ambroise in France. There is also a medal of James IV. in the collar of St. Michael, which, however, is by some suspected to be a forgery. There are various remarkable medals of the unfortunate Queen Mary, most of which, however, appear to have been executed in France. The fine crown of Mary and Henry, in 1565, is exceedingly rare. The coronation medal of Charles II. struck at Edinburgh, 18th June 1663, is the only one ever coined of Scottish gold.

For the reasons already given, we have not thought it necessary to enter more minutely into the history and description of modern coins and medals. We must therefore refer such of our readers as are desirous of more particular information upon this branch of the subject to some of the works we have noticed below.

Vaillant, *History of the Kings of Syria.* Hradouin, *Herodiades.* Froelich, *Annales Regum et Rerum Syriæ.* Corsini, *De Minnifari aliorumque, Armeniæ Regum, Nummis*, &c. Cary, *Histoire des Rois de Thrace, et du Bosphore Cimmerien eclaircie par les Medailles.* Beauvais, *Histoire abregée des empereurs Romains et Grecs*, &c. *pour les quelles on a frappé des medailles*, &c. Cooke, *Medallic History of Imperial Rome.* Le Blanc, *Traite historique des Monnoies.* Banduri, *Numismata Imperat. Rom.* &c. 1718. Republished at Hamburgh, by J. A. Fabricius, 1719. Beger, *Thesaurus, sive Gemmæ, Numismata*, &c. 3 vols. Fol Ejusd. *Regum et Imperat. Roman. Numismata, a Rubenio edita*, 1700. Ejusd. *De nummis Cretensium serpentiferis* 1702. Ejusd. *Numismata Pontificum Roman.* 1703. Sestini, *Descriptio nummorum veterum*, &c. Lips. 1796. Ejusd. *Classes generales*, &c. ibid. 1797. Raschii, *Lexicon universæ rei nummariæ.* Lips. 1785-1805. Eckhel, *Doctrina nummorum veterum.* 8 vols. 4to. and the other works of this author. Pinkerton *on Medals.* (z)

NUNEATON, a market town of England, in the county of Warwick, is situated on the river Anker, and consists chiefly of four streets, which meet at the market-place. The houses are in general neat and well built. The church is a respectable Gothic building, though too small for the population. There is an excellent free school here, founded in the 6th of Edward VI. who endowed it with three closes of ground. The manufacture of ribbons is carried on here to a considerable extent. A portion of the ancient monastery of Nuneaton, comprehending an entire arch, and large fragments of walls, still remains. Population, in 1811, 1095 houses, and 4,947 inhabitants. See the *Beauties of England and Wales*, vol. xv. p. 312.

NUREMBERG, *Mons Noricorum* of the ancients, is a large town of Germany, formerly in the circle of Franconia, but now in the province of Retz, and kingdom of Bavaria. It is situated in a sandy, though well cultivated and fertile plain, and is divided by the river Pignitz, which is crossed by a number of wooden and stone bridges. The town is about three miles in circumference. It is of a quadrangular shape, and is encircled with an old wall, flanked with round towers. The streets are wide, but very irregular and crooked. The houses, which are of stone, have often their end fronts to the street. The principal public buildings, &c. are, the church of St. Marguerite; the church of St. Sebalde, containing a crucifix of brass, weighing 1878 lbs, a crucifix of wood, sculptured by Veit Stofs, and several other curiosities; the church of St. Egidien, rebuilt in 1718, and containing elegant columns, and a beautiful altar-piece, by Van Dyke; the church of the New Hospital, where the relics and ornaments of the empire were formerly preserved; the church of Saint Catherine, where the great navigator Martin Boeheim is buried; the cathedral and parish church of St. Lawrence, containing many admirable paintings upon glass, particularly those of Volkmar; the church of Saint Claire, containing the most ancient painting on glass which exists, bearing the date of 1278; the chapel of Mendel; the seven pillars of Adam Kraft, a religious monument of the 15th century; the Holzschoucherian chapel of St. Sepulchre; the imperial chateau, containing many pictures and articles of great variety and interest, and having in the front court a well of unusual depth; the Hotel de Ville, adorned with many valuable paintings of Albert Durer, a native of Nuremberg; the arsenal; the fountain, in imitation of that of Bologna; the house of correction; the foundling hospital; the Tour d'eau, and the mills for driving the machinery of the copper works. There is at Nuremberg an academy of painting, a college of medicine, a society for promoting industry, and other useful institutions.

Nuremberg possesses many important manufactures. Articles of jewellery and toys are exported to a great amount: pottery, tobacco, playing-cards, and various articles in copper, brass, and ivory, are made here. It possesses also manufactories of woollen. Nuremberg covers 67,443,136 square feet. Its streets are said to be 500 in number; its houses 8000, and its population only about 27,000. East Long. 11° 4′ 15″; North Lat. 49° 26′ 55″.

NUTATION. See Aberration and Astronomy.

O

Oakhampton, a borough and market town of England, in the county of Devon, is situated in a secluded valley, surrounded with hills, near the source of the river Oke, which flows through it. The only building within the town is an old Chantry chapel, which stands in the market-place. It is used for holding the quarterly sessions, and belongs to the corporation. The parish church stands on an eminence at some distance from the town. The ruins of the castle, which is mentioned in Domesday Book, are situated on a huge mass of rock, about one mile south-west of the town: they occupy an extensive area, and exhibit, by their solidity of structure, the former strength and importance of the castle. A lofty peak rises in a magnificent manner from a large conical elevation, opposite to which, on the other side of the river Oke, is a steep wooded bank. The town is governed by eight burgesses, from whom is chosen a mayor, who is also portreeve, eight assistants, a recorder, and a town-clerk. The principal manufacture of the town is that of serges. Population, in 1811, 264 houses, and 1430 inhabitants. See the *Beauties of England and Wales*, vol. iv. p. 239.

OAXACA. See Guaxaca.

OBAN, a town of Scotland, in the county of Argyle, is situated on the Sound of Mull, in a fine semicircular bay, from 12 to 24 fathoms deep, and capacious enough to contain upwards of 500 sail of merchantmen. This bay has two openings, one from the north, and the other from the south, and is protected from the violence of the west winds by the islands of Kerrara and Mull. About 60 or 70 years ago, it was used as a trading station by a company from Renfrew, who built the first house in it. It was some time afterwards constituted one of the ports of the custom-house; and some building leases were granted by the Duke of Argyle and Mr. Campbell, of Dunstaffnage. Since that time, the town has increased with much rapidity. In the year 1778, it derived great advantage from the activity and enterprise of two brothers, of the name of Stevenson, who established different branches of traffic. There is a regular ferry from Oban to Kerrara Island, and thence to Auchnacraig in the Island of Mull. Population 1000. Distance from Inverary about 38 miles west. West Long. 5° 32′. North Lat. 56° 25′.

OBLIQUE ARCHES. See NAVIGATION INLAND.

OBSERVATORY,

A PLACE, as its name imports, destined for observing the heavenly bodies; or, a building, usually erected on an eminence, for the purpose of making astronomical observations.

Almost all nations, in every age, have had their observatories, either public or private, in various degrees of perfection. The determination of the length of the year, and of the return of the seasons for the purposes of husbandry, and other objects, both civil and religious, were absolutely necessary in every well regulated society. These, therefore, would be among the first results deduced from astronomical observations.

When the early navigators were prompted by their spirit for enterprise to visit distant countries, or were driven by storms out of sight of land, the only resource which they then possessed for ascertaining their situation, was a knowledge of the places of the heavenly bodies. But the places of the sun, planets, and fixed stars, for any future period, can only be computed from a series of observations previously made with that view; and it is by astronomy that they are deduced from observation and calculation, and arranged in tables, which are absolutely necessary for reducing observations taken at sea, in order to ascertain the latitude and longitude of the ship, and the variation of the compass.

As navigation, therefore, essentially depends on the determinations made in regular observatories, establishments of this kind have been considered of great national importance, more especially in maritime states, and have therefore been liberally endowed by their different governments. Even private observatories have, in many places, been erected at considerable expense. The number of these has of late years greatly increased; a circumstance which, while it marks the progress of science, does honour to the enterprising character of the age.

Regular observatories are those where instruments are fixed in the meridian, by which, with the assistance of astronomical clocks, the right ascensions and declinations of the heavenly bodies are determined; and thus motion, time, and space, are made to measure each other. Such buildings and apparatus only are called *regular observatories*, though very useful operations are sometimes performed, and important discoveries made, in situations where no instruments can be fixed in the meridian.

HISTORY OF OBSERVATORIES.

Though the information which can be drawn from ancient history is often imperfect; yet we find that all nations, among whom astronomy has been cultivated, have had their observatories at a very early period. It cannot indeed be supposed, until considerable progress had been made both in astronomy and mechanics, that their attempts, either in constructing instruments, or erecting edifices for astronomical purposes, would be very successful. The instruments of ancient astronomers were in general large, and of the rudest construction, and were formed mostly of wood, and sometimes of stone. They consisted chiefly of gnomons, dials, astrolabes, and long tubes like telescopes to assist the sight. For the same purpose also deep wells were sunk in high and dry places, from the bottom of which the stars might be seen in the day time. Most of the buildings for astronomical purposes were of great height, and erected chiefly in very high situations.

We are informed by the ancient historians, that, in Chaldea, a country highly celebrated in the early annals of astronomy, the lofty temple of Belus was used as an observatory. In Egypt, too, the famous tomb of Osymandias was applied to the same purpose. This building is said to have contained a golden circle, adapted to celestial observations, which was 365 cubits in circumference, and one cubit in thickness. It has also been said, that the pyramids of Egypt were employed for astronomical purposes, though this, we think, appears doubtful. In support of this opinion, it is affirmed, that they were built to face the four cardinal points. The great height of these pyramids, no doubt, is favourable for making astronomical observations, whether they be used as gnomons, or for the purpose of ascertaining accurately the times of the rising and setting of the stars. However this may be, it is certain that astronomy was much cultivated in Egypt, particularly in the famous school of Alexandria, where an observatory was built 300 years before the Christian era, and continued to flourish for more than five centuries, under a succession of celebrated names, such as, Hipparchus, Ptolemy, &c.

The Chinese boast of their having made a very early progress in astronomy, both in theory and practice, but their accounts are to be received with much caution. In Hindostan, too, traditions relative to, and vestiges of, ancient observatories, on which ingenious disquisitions have been written, are said to abound. About 260 years ago, five different observatories were constructed by the Hindoos under the reign of the Emperor Mahommed Shah, with a view to reform the calendar by means of astronomical observations; for the accomplishment of which, Jeysing, or Jayasinha, Rajah of Ambhere, was chosen chief astronomer. These observatories were built at Delhi, Benares, Matra, Oujein, and Suvai Jeypoor, and all under the direction of Jeysing. The observatory of Benares will be fully described in a succeeding part of this article, and as all the others were built and furnished on the same plan, the description of one will be sufficient to give a tolerably clear idea of the whole.

The Chinese erected an imperial observatory at Pekin, on the city walls, in the thirteenth century; and, in 1668, Father Verbiest, a missionary Jesuit, having been made president of the tribunal of mathematics, and chief observer, obtained permission from the Emperor Cam-hi to furnish it with proper instruments.

Other observatories were afterwards built in China by the French missionaries, and by the Portuguese Jesuits, who distinguished themselves very much by their labours and improvements in astronomy. The instruments of the Pekin observatory are said to be very large, but the divisions less accurate, and the construction less commodious, than those of the instruments made at that time in Europe. The chief instruments of the Pekin observatory consisted of a sextant eight feet radius, a quadrant six feet radius, an azimuthal horizon, a celestial globe, and an armillary sphere, each six feet in diameter.

The celebrated Copernicus, about 1540, is said to have been the first European who set an instrument in the meridian, though the first regular observatory was erected at Cassel in 1561, by William, Landgrave of Hesse, who furnished it with the best instruments that the age could produce. Here, it is said, he made very accurate observations, in conjunction with his friend and correspondent Tycho Brahé, then rising into fame. The next observatory in Europe, which deserves particular notice, was that of Tycho Brahé himself. It owed its origin, it is said, to the appearance of a new star of the first magnitude in the constellation Cassiopeia. Tycho Brahé was so impressed with the appearance of this extraordinary phenomenon, that he formed the resolution of making a new and accurate catalogue of all the stars, as there had been nothing of the kind done since the time of Hipparchus, who had been stimulated to the same undertaking by a similar cause.

For this purpose, Tycho Brahé proposed to settle at Basle, which had a pure atmosphere, and afforded a ready communication with the learned men of Germany, France, and Italy. But the Landgrave of Hesse wrote to Frederick II. king of Denmark, entreating him to encourage the astronomer to remain in his own country. In consequence of this application, the king assigned to him the small but fruitful island of Huen, in the Sound, as a fit situation for an observatory, and conferred on him other favours. His majesty, besides, undertook to defray the expenses of building and furnishing the observatory, with a munificence which has immortalized his name. The first stone of the observatory was laid on the 8th of August, 1576, and the place was called Uraniburg. It consisted of a building of sixty feet square, and seventy feet high, with four towers, all adapted to astronomical purposes.

It was furnished with a valuable collection of instruments, many of which were invented by the astronomer himself. He had numerous assistants, whom he supported and instructed. Among his instruments was a celestial globe of six feet diameter, said to have cost one thousand pounds. It was after his death carried to Prague; afterwards to Neis; and lastly, to Copenhagen, where it was burnt in the great conflagration of 1728. Many of the instruments of this great astronomer were long carefully preserved, but have been gradually lost; and his favourite residence Uraniburg, which in his time was visited by kings and princes, has been long a heap of ruins, so that its correct situation is but imperfectly known. Relative to this place, Delambre has written an interesting memoir in the *Connaissance des Tems*, for 1816.

His celebrated sextant has been consecrated in the heavens as a constellation, under the breast of the lion. On large globes and atlasses, it is marked Sextans Uraniæ, but on common ones Sextans.

English Observatories.

The royal observatory at Greenwich, from the importance of the observations and discoveries made there, claims our first attention. It was built and endowed by king Charles II. who, as Bailly observes, knew well how essential a knowledge of astronomy was to a maritime and commercial people. It was erected on the site of the ancient moated tower of Duke Humphrey, the uncle of Henry VI. and the first stone of it was laid on the 10th of August, 1675, by Mr. Flamsteed, who had been appointed astronomer-royal. The words of his commission were, "To apply himself with the utmost care and diligence to the rectifying the tables of the motions of the heavens, and the places of the fixed stars, in order to find the so much desired longitude at sea, for perfecting the art of navigation." Every scientific navigator knows with what success this commission has been fulfilled by the labours of each succeeding astronomer-royal. It is situated on the highest part of Greenwich Park, at about 160 feet above low water mark, where the soil is peculiarly favourable for such an institution, being of a flinty gravel, through which the rain readily passes, thereby rendering the atmosphere generally dry, which contributes very much to the preservation of the instruments, as well as to the unifomity of the refraction.

The whole of this establishment comprehends two principal buildings, one of which constitutes the observatory, and the other the dwelling-house of the astronomer-royal. The observatory is a low oblong edifice, running east and west, and containing four principal apartments on the ground floor. The most easterly room has been lately fitted up for the reception of a very fine transit circle, by Troughton, and a valuable clock by Hardy.

The next apartment is the transit room, having a double sloping roof, with sliding shutters, opening both north and south, with great ease, by means of pulleys. The transit instrument is eight feet long, having an axis of three feet, and is suspended on two stone pillars. This instrument is rendered famous in the history of astronomy, as having been used by Halley, Bradley, and Maskelyne. It was made by Bird originally, and has been successively improved by Dollond and Troughton. The astronomical clock, in the same room, attached to a stone pillar, was made by Graham, and has been improved by Earnshaw.

The third apartment is at present the assistant observer's library, and place for calculation. The most westerly apartment of the whole building is the quadrant room, in which is erected a stone pier, running north and south, to which are attached two mural quadrants of eight feet each. That on the eastern face, intended to observe objects on the southern part of the meridian, was made by Bird; and the other, for observing on the northern part of the meridian, was made by the celebrated Graham. On the western wall is suspended the famous zenith sector, with which Bradley made the observations at Kew, that led him to the discoveries of the aberration of light, and the nutation of the earth's axis.

To the south of the quadrant room is a small wooden building for making occasional observations in any direction, where the use of a simple telescope, and an accurate knowledge of time only, are required. It is furnished with sliding shutters on the side and roof, to view any part of the hemisphere, from the prime vertical down to the southern horizon. It contains some good telescopes, particularly a forty-inch achromatic, with a triple object-glass, and a five feet achromatic, by Dollond; also a six feet reflector, by Sir William Herschel.

To the north of the observatory, and east of the house, are two small buildings, covered with hemispherical sliding domes, in each of which is an equatorial sector by Sisson, and a clock by Arnold, which are chiefly used for observing comets. The lower apartments of the dwelling-house are occupied by the astronomer-royal, over which is a large octagonal room, which contains a great variety of astronomical instruments, with a library consisting chiefly of scarce and scientific books. On the top of the house is a camera obscura, very well situated for exhibiting views of many interesting objects.

In Flamsteed's time a well was sunk in the south-east corner of what now constitutes the garden, behind the observatory, for the purpose of seeing the stars in the day time, and observing the earth's annual parallax. It was a hundred feet deep, with stone stairs down to the bottom; but it has been long arched over, as the improvements in the telescope have rendered it unnecessary for astronomical purposes.

The observations which have, in general, been made at the Royal Observatory, in later times, are universally allowed to possess an unrivalled degree of accuracy, and the fine instruments executed by the celebrated Troughton, now in the hands of Mr. Pond, will, we confidently expect, maintain their former character. Indeed, the number of accurate astronomical observations which have been made here are enormous. "In short," it may be said, with Delambre, "of the four volumes of observations which Maskelyne has published, that if, by a great revolution, the sciences should be lost, and that this collection only were saved, there would be found in it materials sufficient to rear almost an entire new edifice of modern astronomy." One cannot indeed enter this place without being impressed with a feeling of reverence for it, as a temple dedicated to the noblest and most sublime of all the sciences.

Subjoined are the names of the astronomers who have officiated here in succession: Flamsteed, 43 years; Halley, 23 years; Bradley 20 years; Bliss, two years; and Maskelyne 46 years.

Oxford observatory is a most magnificent structure, worthy of the celebrity of that distinguished university. It was begun in the year 1772, from very ample funds bequeathed by Dr. Radcliffe, and upon a piece of land given for that purpose, by the Duke of Marlborough. The transit instrument, which is ten feet long, shows very small stars in the day time, and is said to have cost 150 guineas. The zenith sector also is a fine instrument, and cost 200 guineas; and there are two mural quadrants of 600 guineas value.

Herschel and Dollond have also furnished it with very admirable telescopes, and Skelton with a clock of excellent workmanship. It was built under the direction of Dr. Hornsby, professor of Astronomy in the university, who observed here for many years. He has been succeeded by Dr. Abram Robertson, the present worthy Savilian professor of astronomy.

The observations are all registered, and consist chiefly of the right ascensions and zenith distances of the sun, moon, planets, and fixed stars. In Dr. Hornsby's time, the series of observations was sometimes broken off from ill health; but as an assistant observer has been lately added, the observations will not, in future, be liable to interruption.

It has been proposed to erect a splendid observatory at Cambridge, every way worthy of that distinguished university; and the necessary funds have, in a great measure, been provided for that purpose. The observatory syndicate, it appears, have reported to the senate of Cambridge, that the arrangements with St. John's College, for the site of the observatory, although not completed, are yet considerably advanced, and will probably be soon brought to a termination; that Messrs. Munday and Bushell have entered into a contract with the syndics, by which they engage, before the end of October, 1823, to complete the buildings, faced with stone throughout, agreeably to Mr. Mead's plans and specifications, for the sum of 8497*l.* 8*s.* 6*d.* The excavations and levelling of the ground for the new observatory have just commenced.

We have not been able to ascertain when such a valuable appendage to that university will be completed. It is only, however, by multiplying the places at which very accurate astronomical observations are made, that the science of astronomy can be now perfected, and we sincerely wish success to the completion of this useful undertaking.

The observatory at Slough, near Windsor, where Sir William Herschel observes, will for ever claim a place in the history of distinguished astronomical institutions. In its plan and apparatus it differs from all other observatories, and exceeds them all in the number and importance of its discoveries.

It may be remarked, in describing this observatory, that the labours of Sir William Herschel have a peculiar interest, from the circumstance that his discoveries are all the result of his own inventions. For, to a profound knowledge of astronomy, he adds that of optics in a very eminent degree, both in theory and practice, by which he has been enabled to cast and polish mirrors for reflecting telescopes, greatly superior to any other, not only in magnifying power, but in collecting or preserving light, by which vision is wonderfully extended, and which he very expressively denominates "the power of penetrating into space." The telescopes, which are all made under his direction, are of various sizes, from two to forty feet in length, and the apparatus and machinery upon which they are mounted are also of his own contrivance, and exhibit a very ingenious display of mechanical invention.

As his larger instruments could not be conveniently managed within the cover of a building, they are mounted in the open air, where they stand pointing to the heavens in different directions, and make a most magnificent and impressive appearance.

His largest telescope, forty feet long, and five feet in diameter, has been fully explained in our article Optics, in this volume, and represented in Plate CCCCXLI. Two of his smaller telescopes will always be famous in the history of astronomical discovery. The first is a two feet Newtonian reflector, with which his sister, Miss Caroline Herschel, discovered six comets; and the other is his seven feet reflector, with which he discovered the Georgian planet, or Uranus, at Bath, in 1781. This telescope, in consequence of the discovery, has been made a constellation in the heavens, with the universal approbation of astronomers. It is placed between Gemini, the Lynx, and Auriga, and contains 81 stars. In Bode's Atlas it is engraved with its apparatus, and marked Telescopium Herschelii. Sir William Herschel is now in his eighty-fourth year, and was born at Hanover, on the 15th of November, 1738, a period which will be ever memorable in the history of astronomy.

It cannot be supposed that this eminent astronomer can contribute much more to the improvement of his favourite science; but we look forward with sanguine hopes that his son will continue to follow his father's footsteps with that distinguished success with which he has commenced his scientific labours, and which his eminent analytical powers and patient habits of research, entitle us to expect.

The observatory in Richmond Gardens is a very beautiful structure, and has an excellent apparatus. It was built in 1768, by order of his late majesty, George III. who, it is said, made several observations here, particularly the transit of Venus in 1769. It contains a fin transit instrument, a zenith sector, and a mural arc, together with several good telescopes, particularly a ten feet reflector of Sir William Herschel's. There is a superb equatorial on the top of the building, which is covered with a moveable roof. There are also two fine orreries, with an excellent collection of philosophical instruments, and some cases of minerals and other natural curiosities. It was built under the direction of Dr. Demainbray, and has been for some years under the care of Mr. Rigaud.

There is an observatory at the Royal Naval College at Portsmouth, under the direction of Professor Inman, which is found to be very useful in teaching the students practical astronomy, and in finding the rates of marine chronometers.

At Christ's Hospital in London, Mr. Wales, who had served under Dr. Maskelyne and Captain Cook, erected a small observatory at his own expense, when he became master of the royal mathematical school there.

At Somerset House, too, the Royal Society have a small observatory, which is generally superintended by the clerk for the time being.

Besides the above, there are, and have been several excellent private observatories, as that at Blackheath, where Stephen Groombridge, Esq. observes, to whom astronomers are indebted for several correct tables of atmospherical refractions. Blenheim, belonging to the Duke of Marlborough; the Rev. Mr Catton's, at Cambridge, Chisel Hurst, the Rev. Francis Wollaston; Derby, William Strutt, Esq.; East Sheen, the Rev. William Pearson; Finsbury Square, Dr. Kelly; Godwood, the Duke of Richmond; Gosport, Dr. William Burney; Hackney Wick, Colonel Beaufoy; Hayes, William Walker, Esq.; Highbury Terrace, Captain Huddart; Hoddesdon, William Hodgson, Esq.; Islington, Gavin Lowe, Esq.; Paragon, Southwark, James Strode Butt, Esq.; Park-lane, Sir Henry Englefield, Bart.; Rose Hill Sussex, John Fuller, Esq.; Sherburn, Earl of Macclesfield; St. Ibbs, Hitchin, Professor Lax; and Woolwich, Royal Military Academy. Mr. South and Mr. Bailey have also established observatories, and furnished them with excellent instruments.

Scottish Observatories.

The New Edinburgh Observatory is built from a design of William Henry Playfair, Esq. architect, nephew of the late celebrated Professor Playfair; and it shows, in its exterior appearance, as well as his other works, that he possesses no small share of the classical elegance of his distinguished relative. From an inspection of the plan and description, we think it will be found to be equally commodious and well fitted for the purposes for which it is intended, as it is remarkable for its elegant simplicity of design. It is situated on the top of the Calton Hill, a considerable eminence, which may be now considered as within the city of Edinburgh. Proposals had been early made for founding an observatory, though the first scheme for erecting a building of this kind was actually formed in the year 1736; but the commotion occasioned by the execution of Captain Porteous by the populace, a circumstance now immortalized by our great novelist in the "Heart of Mid-Lothian," prevented the completion of the design. It was again revived in 1741, at which time the Earl of Morton gave the sum of 100*l*. Sterling, for the purpose of erecting an observatory; and the celebrated Maclaurin, with the Principal and some of the Professors of the university, were appointed trustees for managing this sum, together with what might be otherwise collected. Mr. Maclaurin himself, with a liberality characteristic of an enlarged mind, added to the above sum the profits arising from a course of lectures that he read on experimental philosophy, which, with other small sums, amounted to about 300*l*. The lamented death of this eminent professor in 1746, however, put a stop, for the second time, to the execution of the design.

The famous James Short, well known for his improvements in the construction of reflecting telescopes, in conjunction with his brother, now attempted to erect the building; but the progress of the unfortunate observatory was again interrupted by the death of Mr. Short, which happened in 1768.

About the year 1776, the money, which had accumulated to 400*l*., was proposed to be expended in building the observatory. A plan of the intended edifice was designed by Mr. Craig, architect, and the foundation stone of the building was laid by Mr. Stodart, Lord Provost of Edinburgh, on the 25th of August, 1776. It stood in this situation for many years, when, in 1792, it was completed by the magistrates; but in a style far inferior to what the utility of such an institution deserved. Being possessed of few instruments, and provided with no funds for procuring any, it remained almost in a ruinous state till 1812, when a more fortunate attempt was made to establish an observatory on a respectable footing, by the formation of an astronomical institution in Edinburgh. The Astronomical Institution took its origin from a few public-spirited individuals, who formed themselves into a society under this title on the 30th of May, 1812; and the magistrates gave to the association the ground and buildings on the Calton Hill, formerly destined for an observatory, on the condition of their not being applied to any other purpose, at the same time granting a seal of cause, to enable them to hold property, and to enjoy the privileges of a corporation.

The objects of this institution are to establish, 1st, A scientific observatory, furnished with all the instruments required for the nicest purposes of astronomy. 2d, A popular observatory, furnished with instruments connected with astronomy, of general and easy use, calculated for students and amateurs; and also with globes, maps, atlasses, charts, and books, adapted to the promotion of nautical and geographical science. And, 3d, A physical cabinet, furnished with a complete meteorological apparatus, and with such other instruments and books as may be deemed useful for the advancement of physical science.

The property of this institution is held in transferable shares of 25 guineas each, which, besides his own admission to the popular observatory at all times, entitles a proprietor to introduce a friend, who may also be admitted on his written order. The second class of subscribers, who pay by annual instalments, have only the right of personal admission. The management is vested in a council, consisting of a president, vice-president, treasurer, secretary, and an observer, with 18 directors, six of whom go out annually by rotation.

In pursuance of these objects, the directors fitted up the top story of the old building, a little to the west of the original observatory, now taken down, with a camera obscura, which forms the chief object of attraction to visitors; and the room under it contains, among other things, a four feet achromatic telescope by Tulley, some smaller ones, and a pair of twenty-one inch globes. The celebrated Troughton was also engaged to make a mural circle of five feet diameter, and a transit instrument of ten feet, of which the estimated cost is about 1000 guineas.

The magistrates of Edinburgh having deposited a small transit instrument, which they had procured from Troughton, for regulating the city clocks, in the apartments of the institution, a room was erected for its reception in 1814, in which was also placed an astronomical clock, by Mr. Thomas Reid.

The new observatory, a little to the east of the former, was founded on the 25th of April, 1818, by Sir George Mackenzie, Vice-President, in the absence of Professor Playfair. In the foundation stone were deposited copies of the Edinburgh newspapers, almanack, and current coin of the country, and a platinum plate, on one side of which were engraved the names of the members, and on the other this inscription:

Speculae
Ad siderum cursus aliaque coelestia contemplanda
Sumptibus suis extruendae
Primum lapidem ponendum curarunt
Institutionis Astronomicae Edinensis Sodales;
vii. cal. Maj aerae Christianae an. mdcccxviii.
Georgio Tertio an. lviii. regnante,
Period. Julian. IↃↃCDXXXI.
Gulielmo Henrico Playfair, Architecto;
Ne diutius
Urbi clarissimae
Scientium omnium pulcherrimam atque amplissimam
Excolendum facultas deesset.

The observatory, of which we have given an elevation in Plate CCCCXXV. Fig. 1. and a ground plan in Fig. 2. is a cross of sixty-two feet, with four projecting pediments of twenty-eight feet each, supported by six columns of the Doric order fronting the four cardinal points. In the centre is a moveable dome, thirteen feet in diameter, under which is a pillar of solid masonry, of a conical form, six feet in diameter at the base, and nineteen feet high, intended for a portable astronomical circle, or equatorial, for making observations out of the meridian. To the east are stone piers for the transit instrument and clock; and in the west end others for the mural circle and clock. All these are founded upon the solid rock. A small gallery is formed round the central pillar for the accommodation of the observers, who have also a room in the northern side of the building.

In the ground plan on the east side, *a*, *a*, are the slits or openings in the walls and roof, through which the celestial bodies are observed by the transit instrument when in the meridian; *b*, *b*, are the stone pillars on which the transit is supported; *c* the stone to which the transit clock is attached; *d* a block of stone, on which an artificial horizon may be placed, when observations are taken, by the method of reflexion, as described by Sir Thomas Brisbane in the *Edinburgh Philosophical Transactions*, vol. ix. p. 1, and which, when not used, is covered by a board fitted into the floor. In the western side, *e*, *e*, are openings or slits as before; *f* the stone pier, to which the great mural circle is to be fixed; *g*, the clock pier; *h*, a place for an artificial horizon as before: *i*, is the conical pillar, over which is placed the moveable dome, having an opening, *l*, in the elevation, as usual, for the purpose of observing; *k*, is the observer's room; and *m*, is the entrance in the front.

It is sincerely to be regretted by every friend to science, as well as to the scientific reputation of Edinburgh, that, from want of funds, proper instruments have not yet been provided, nor a salary for an observer, that might enable him to devote his attention entirely to the pursuits of astronomy.

In the year 1807, a number of gentlemen formed themselves into a society for the promotion of astronomical science, and have since received a Seal of Cause from the Magistrates and Council of Glasgow, erecting them into a corporate body for that purpose. The funds of this society have been raised by 250 transferable shares of 20 pounds each, which are held as heritable property. The observatory stands on Garnet Hill, about a mile north-west from the cross. The situation is unquestionably the best which could have been chosen in the neighbourhood of Glasgow. The designs, which are in the Egyptian style of architecture, were furnished by Mr. Webster of London. The building is divided into three compartments; the centre one constitutes the scientific observatory, and is surmounted by a revolving cupola; the east division forms the popular observatory, where the subscribers have the use of instruments, and treatises connected with the science; and the west compartment is fitted up for the accommodation of the observer, and other purposes. In the scientific observatory there are three massive stone pedestals; to one of which a sidereal clock is attached; on another pedestal, twenty feet high, rising without the base of the revolving cupola, is placed an excellent azimuth and altitude instrument, which is capable of being fitted up as an equatorial; on the other pedestal is to be placed a large mural circle, prepared by Troughton. The popular observatory is provided with a complete set of instruments for making astronomical observations of the more ordinary kind. A Herschelian telescope, ten feet long, is used in the terrace, in front of the centre compartment of the observatory, where the projecting wings of the building afford a shelter from the wind. There are several other telescopes of different kinds, as well as globes, sextants, theodolites, &c. in this part of the observatory; a fourteen feet Herschelian telescope is placed on the roof; an anti-room is occupied by a camera obscura, and a solar microscope; and other useful instruments are to be immediately added to this department of the observatory. This valuable institution has been honoured by the approbation of the most eminent astronomers in the country, and, we hope, will tend to the more general diffusion of a knowledge of astronomy.

There is also in the College Gardens a small observatory, provided with the usual instruments, for the use of the professor of practical anatomy, but which do not require any separate description.

The observatory of Sir Thomas Brisbane has already been noticed, in our history of ASTRONOMY.

At Aberdeen, in 1694, a lofty square tower was erected upon the top of the west wing of the College, for the purpose of an astronomical observatory, though we are not certain whether it ever was provided with proper instruments.

Soon after the appointment of Dr. Copland to the natural philosophy chair, he formed the design of erecting an observatory; and in 1781, succeeded in raising, by subscription, a fund for defraying the expence of the building and necessary apparatus, which was expended in the erection of one on the Castle-Hill. In 1794, this was taken down, in consequence of government wanting the ground for barracks; and in 1797, a new one was constructed on the west wing of the college, to which the instruments were removed. The principal room is 40 feet by 18, and adjoining to this is a small balcony for making observations out of the meridian.

Belonging to this observatory there are several good instruments; a transit of four feet by Ramsden; a quadrant of two feet radius by Troughton; an equatorial by Sisson; a clock with a gridiron pendulum; an assistant clock; a good achromatic telescope of four feet by Dollond, with a divided object glass micrometer; a reflecting telescope of ten feet; a fine theodolite of sixteen inches by Troughton, constructed on the same principles as that used in the trigonometrical survey of Britain. There is also here, executed by Troughton, a very fine scale of equal parts, divided by micrometer microscopes, to ten thousandths of an inch, similar to those of Sir George Shuckburgh, and Professor Pictet of Geneva, the only three ever executed by that artist.

Irish Observatories.

In Ireland, there have been two observatories fitted up and finished on a great scale; the one at Dublin, and the other at Armagh.

The observatory belonging to Trinity College, Dublin, was begun in 1783. It was founded by Dr. F. Andrews, provost of that college, who bequeathed a large sum for that purpose. The apparatus consists of a transit of six feet focal length, with a four feet axis, having an aperture of 4½ inches, and provided with three different magnifying powers, extending as far as 600. There is also an entire circle of eight feet diameter and moving on a horizontal axis, for measuring chiefly meridian altitudes. In addition to these, there are an equatorial instrument, with circles of five feet in diameter, and an achromatic telescope mounted on a polar axis, and carried by a heliostatic movement. The clocks were furnished by Mr. Arnold, without any limitation of price.

The situation chosen for the observatory is upon an elevated ground, about four miles north-west from Dublin. The foundation is a solid rock of limestone, of several miles in extent, and the soil is of the most favourable description, being a calcareous substance, called limestone gravel, which absorbs the rain remarkably fast, and thus contributes to render the atmosphere generally dry. The plan of the edifice unites at once elegance and convenience. In the centre is a magnificent dome, three stories high, with a moveable roof for the equatorial instrument, which is placed on a pillar, sixteen feet square, of the most substantial masonry, and surrounded by a circular wall at a foot distance, supporting the moveable dome as well as the floors, which in no part touch the pillars, to prevent any motion being communicated from the floor or wall to the instrument. The aperture for observation in the dome is two feet and a half wide.

But the most important erection belonging to this establishment is behind the principal building, and at right angles to it, in order to obtain an uninterrupted view of the horizon both towards the north and south. This is the meridian and transit room, which contains both the transit instrument and circle. The dimensions of this room are 37 feet long, 23 feet broad, and 21 high. For the purpose of supporting both instruments on a firm basis, five pillars of Portland stone have been erected, and the floor is so constructed as to let all the pillars rise through it totally detached. The clocks are also attached to pillars of the greatest steadiness. They were made by Arnold, who exerted all his skill in their construction, and finished them in a masterly style. The pallets are of ruby, and all the last holes of the movements are jewelled. The suspension springs are of gold, with Arnold's five-barred pendulum, and cheeks capable of experimental adjustment, so as to make all the oscillations isochronous, whatever may be the excursion of the pendulum.

The Rev. Dr. Usher, the first astronomical professor, did not long enjoy the pleasure arising from his labours in astronomy, but died in 1790, before the instruments had been all fitted up. He was succeeded by the Rev. Dr. Brinkley, who had for some time been a pupil of the late Dr. Maskelyne. Dr. Brinkley studied at Cambridge, and had distinguished himself there by his profound analytical investigations. He has since greatly enriched the *Philosophical Transactions*, and the *Transactions of the Royal Irish Academy*, by his valuable mathematical and astronomical papers.

From observations made with a new eight feet circle, by Ramsden and Berge, important results have been expected, particularly on annual parallax, the aberration of light, and astronomical refraction. Dr. Brinkley has been for some time engaged in a series of observations, with a view to explain the cause of those variations which he has found in the zenith distances of certain stars at different times, which do not seem explicable by any cause yet known. He has found a difference between the zenith distances of α Lyræ, when in opposition and conjunction, which may be explained by a parallax of about two seconds.

The new transit, or meridian circle, erected lately at Greenwich, possesses considerable advantages for such purposes, and great hopes have been formed of the combined operations of these two instruments. In a letter to the writer of this article, however, Dr. Brinkley expresses great confidence in his having determined, with accuracy, on principles which appear unexceptionable, the parallax of some of the fixed stars. He also thinks, that a circle with a vertical axis possesses several advantages over the mural circle, and that the method of referring each star to the zenith point, is preferable to that of comparing them with fundamental stars as practised at Greenwich.

At Armagh, the metropolitan city of Ireland, and formerly the seat of a large university, an observatory was erected and endowed, in 1793, by the Most Reverend Richard Lord Rokeby, then primate of Ireland. It is erected on the summit of a gently rising hill, about ninety feet above the general level of the town. In the tower adjoining the dwelling-house, there is a very fine equatorial by Troughton, fixed in a large pillar, which is raised to such a height that the instrument in the dome overlooks all the buildings. To the east of the house there is a range of buildings, adapted for a transit room, and other astronomical purposes. The other principal instruments, besides the equatorial and transit, are, a ten feet sextant by Troughton; a ten feet reflecting telescope by Sir William Herschel; a five feet triple object-glass achromatic telescope by Dollond; and a fine night glass, on an equatorial stand. The clocks are the workmanship of Earnshaw of London, and Crossthwaithe of Dublin.

In this establishment, a liberal income is allowed the principal astronomer, and a good salary to his assistant. It has been superintended, from its commencement, by the Rev. James Archibald Hamilton, D. D. Dean of the cathedral church of St. Coleman, Cloyne. The registered observations are those made with the transit instrument and equatorial, accompanied with an account of the state of the barometer and thermometer. Of these, a series of about 18 years is preserved. The right ascension of the sun and moon, compared with the fixed stars, are regular and unbroken; but their north polar distances have not been so regularly taken, as they are only observed by the principal astronomer, whose pastoral duties must occasionally interfere with his astronomical labours.

French Observatories.

The Royal, or Imperial Observatory, as it is sometimes called, of Paris, was built in 1667. It is 160 feet in front, by 120 in breadth, and 90 feet in height. Its vaults are also 90 feet deep, so that it is 180 feet from top to bottom. A particular description of the building is given by Blondel, and the arrangement and disposition may be found in Bernoulli's *Lettres Astronomiques*, in Lalande's *Astronomie*, and in Monnier's *Histoire Celeste*.

In addition to the original building, new rooms have been constructed, close by the side of the observatory, where a large transit and circle by Ramsden have been fitted up. In 1788, new vaults were made, and a small observatory formed on the top of the building, which commands an extensive view of the horizon. There Louis XVI. established three observers, in order to prevent, as much as possible, an interruption in the series of observations.

In 1792, Lalande gave the following account of other observatories, which may be noticed here as interesting in the history of practical astronomy.

The astronomers of the academy had, besides the Royal Observatory, several private ones erected in different parts of Paris, as the former was not sufficient for the accommodation of all. That of Monnier has been, since the year 1742, in the garden of the Capuchins. That of the Marine, which Joseph de Lisle used in 1748, at the Hotel de Clugny, has been occupied by Messier. That of Lacaille is still in existence at the Mazarine College. That of the palace of Luxembourg is above the Port Royal, where Joseph de Lisle once observed, and which Lalande occupied also for some time. M. Pingré's, at the Abbey of St. Généviève, was built in 1756. Cagnoli's is in the Rue de Richlieu, which that able and active astronomer built, at his own expense, in 1785, when he resided at Paris.

The observatory of the military school was built for M. Jeaurat in 1768, and was afterwards occupied by M. d'Agelet. The late M. Bergeret, Receiver-General of Finances, had constructed, in 1774, a large mural quadrant, of eight English feet, the last and best instrument made by the celebrated Bird. This instrument was obtained by the Military Academy, as well as an excellent transit instrument, and a parallactic telescope. M. d'Agelet made a great number of observations there, from 1778 to 1785, when he left it to make a voyage of discovery with La Perouse. In 1788, the changes made in the Military School occasioned the demolition of this observatory; but it has been re-built a little more to the west, with all necessary attention, so that it is now the most complete observatory at Paris. Lalande, having received the direction of it, began, in 1789, to make a series of observations. M. le François Lalande, his relation and pupil, has also made a prodigious number of observations, and he observed, in 1791, more than ten thousand northern stars, with excellent instruments. An observatory was built in 1775, at the College Royal, for the use of the Professor of Astronomy in this celebrated school. M. Geoffroy d'Assy built, in 1788, an observatory at his house, Rue de Paradis, which was used for some time by Delambre.

Such was the state of the observatories at Paris in 1792. At present, Delambre is the chief of the imperial university. Messier succeeded him at the Royal College, now the College of France. M. Burckhardt is astronomer at the Military School; Le François Lalande resides at the Place de Cambray; and Bouvard and Arago superintend the Imperial Observatory.

The Marseilles Observatory has been rendered famous by the observations of Sylvabelle, and by the number of comets observed in it by M. Pous.

The Toulouse Observatory is deserving of notice from the zeal and ability with which M. Darquier cultivated astronomy. In this city, too, observatories have been built by M. Gaupuy and M. Bonrepos. Here, indeed, astronomy has been more successfully cultivated than in any other provincial city of France. The principal observatory is under the superintendence of M. Vidal.

At Lyons, the College Observatory, which was built by Father St. Bonnet, is a very fine edifice, on an elevated situation.

At Dijon, M. Necker, about the year 1780, converted the tower of the King's Lodge to an observatory, where the Abbé Bertrand made very accurate observations.

At Montpellier there has long been an observatory on one of the towers of the city, in which M. Ratte and Poitevin have distinguished themselves as very accurate observers.

At Beziers, the bishop's palace was converted into an observatory, where some interesting observations have been made by M. Bouillet, particularly on the ring of Saturn.

At Avignon, an observatory was built by Father Bonfa, in 1683. He has been succeeded by a number of able observers.

At Strasbourg, Brackenhoffer, Professor of Mathematics, had an observatory, in which he has been succeeded by Herrenschneider in 1790.

At Bordeaux there is an observatory, 75 feet high, and 20 feet square. It is situated in the finest part of Tournay, and here M. Turgot procured a complete set of observations to be made on the length of the pendulum oscillating seconds, upon which Boscovich has written an interesting memoir.

At Brest, a small observatory was built for the Naval Academy, and plans have been set on foot for erecting a more considerable edifice.

At Rouen, there is an observatory belonging to M. Bouin, in which there has been made a number of good observations.

At Montauban, the Duc de la Chapelle founded an observatory, where he himself has made many accurate and interesting observations, particularly of the transit of Venus over the sun in 1769.

German Observatories.

In Germany, a great number of observatories have been established, and that country has produced several very able astronomers.

At Berlin, Frederick I. King of Prussia, founded an observatory in 1711, under the direction of Leibnitz, at that time President of the Academy of Sciences there. It consists of a large, steady, square tower. It was here where Grischow and Kies made various observations, and where Lalande observed about 1752. He raised great stone pillars, to which were attached the north and south mural quadrants. Frederic II. added a very fine building to it, in which the meetings of the Academy of Sciences of Prussia were held. M. Bode, who has been many years the astronomer-royal here, has distinguished himself as an accurate observer, and as the publisher of the most complete celestial atlas extant, accompanied with a well arranged catalogue of the stars, and an interesting history of the constellations.

At Konigsberg there is an observatory under the able direction of M. Bessel, who, to his former instruments, has added a great meridian circle by Reichenbach, of which a plan and description is given in the first volume of Bessel's astronomical observations. He has given a small, though very accurate, catalogue of the principal fixed stars.

At Vienna, the Empress Maria Theresa built an observatory for the university, about the year 1755, and furnished it with many excellent instruments. There is also one belonging to the college, built and endowed by the Jesuits in 1735, furnished with very fine instruments, chiefly made by British artists, and superintended by very able observers. The reputation of the university observatory was maintained for many years by the Abbé Maximilian Hell, who conducted the Ephemeris of Vienna, which is now continued by M Treisnecker, his successor.

At Gottingen there is an observatory, memorable by the labours of Tobias Mayer, and by those more recently of Harding, who discovered Juno in 1804. Here, too, that able mathematician and astronomer, M. Gauss, observes, who has been lately provided with new instruments, particularly a fine repeating circle by Reichenbach, which, without doubt, he will turn to good account.

At Manheim there is an observatory, containing excellent instruments, though the building is inadequate. There is a three-feet repeating circle by Reichenbach, an eight-feet mural quadrant by Bird, a six-feet transit by Ramsden, &c. M. Schumacher was superintendent of it from 1813 to 1815, when, at the death of Bugge, the King of Denmark called him to Copenhagen. It is now under the care of M. Nicolai.

At Nuremberg an observatory was built in 1678, and another in 1692, where Zimmert and Wuzzelbau have distinguished themselves as observers.

At Cassel an observatory was built, in 1714, by Charles I. Landgrave of Hesse, heir to the lands and taste of William, the early friend of Tycho Brahé.

At Griessen there was built an observatory, in 1740; and another in 1768, at Outsburg, in Franconia.

At Leipsic, in 1788, another was built upon an old tower of great stability. Observatories have also been erected and supported with credit at Cremsmunster, Lambach, Polling, Prague, and Gratz.

At Bremen there is an observatory belonging to Dr. Olbers, an eminent physician, who has immortalized his name by the discovery of two new planets, Pallas and Vesta.

At Lilienthal, near Bremen, M. Schroeter, governor of that district, erected an observatory about the year 1786, and furnished it with excellent instruments. He is highly celebrated as an accurate and interesting observer, particularly of the surfaces and rotations of the planets and of the moon.

At Seeberg, near Gotha, a very considerable observatory was built in the year 1788, by the Duke of Saxe Gotha, of which M. Zach, now Baron Zach, was appointed superintendant, who has distinguished himself as a profound and accurate astronomer. This observatory is reckoned one of the most beautiful and complete in Europe, and is situated on a fine elevation about a league from the town. There is here a large transit, with two mural quadrants, of eight feet radius, and a circle of eight feet in diameter, all by Ramsden and his successor Berge.

At Brunswick there is an observatory that belonged to M Gauss, now of Gottingen, well known for his determinations of the orbits of the new planets, and other important labours.

Italian Observatories.

In Italy, practical astronomy has been cultivated with much assiduity and success during the last century; chiefly by ecclesiastics, and particularly by the Jesuits.

At Rome, Cardinal Zelada constructed, at his own expense, on the southern part of the Roman College, a very fine observatory, with the large sector of Father Boscovich, and other instruments, by Ramsden and Dollond. The Abbé Calandrelli observed here with great attention and accuracy for many years. Other buildings of a similar description have been erected in different parts of Rome.

At Bologna a magnificent observatory was built in 1714, in the Palace of the Institute, by the munificence of the celebrated Count Marsigli; and Pope Benedict XIV. afterwards gave a large sum of money towards the purchase of instruments. Here a succession of able astronomers have observed, among whom may be enumerated Manfredi, Zanotti, Canterzani, &c.

At Pisa an observatory, in the form of a spire, was built in 1730, at the expense of the university, and supplied with excellent apparatus made by Sisson, Short, Graham, &c. Perelli observed here for many years, and had for a successor M. Slop, who published an excellent collection of observations in 1789.

At Milan there is an observatory, which is reckoned one of the most useful in Italy. It was built in 1765, at the cost of the College of the Jesuits, chiefly through the zeal of Father Pallavicini, and under the direction of Boscovich, who also contributed liberally to the expense. The instruments have been made with great care by the principal English and French artists. Among the observers may be reckoned Reggio, Oriani, and Cesaris.

At Florence, Father Ximenes erected an observatory at the College of Jesuits, which contains a quadrant by Toscanelli, larger than any other known, with which he made observations to prove the secular diminution of the obliquity of the ecliptic. At his death he bequeathed the whole to the college. In 1772 the Grand Duke Leopold built an observatory, which was superintended by Fontana; and several fine instruments, by Ramsden, were added to it in 1786.

At Turin, Father Beccaria erected a small observatory for his own use: but in 1790 a large one was built, at a very considerable expense, by the King of Sardinia, at the Royal College of Nobles, and the direction of it given to the Abbe Caluso.

At Venice an observatory was constructed by Father Panigai, and a small one near the town by M. Miotti. One was also built at Parma by Father Belgrado, and another at Brescia by Father Cavalli.

At Verona, Cagnoli, eminent both as a mathematician and an astronomer, erected an observatory at his own expense, in 1787, and placed in it the best instruments, with which he has made very accurate and important observations, particularly on the precession of the equinoxes, and on the places of 473 northern stars, and 28 southern, of which he has made a catalogue. In these determinations he has been perhaps more attentive than any other astronomer, to the minute changes of refraction, and to the aberration of light.

At Padua there is an observatory, which, in 1778, was furnished with instruments, chiefly made by Ramsden. It has been many years under the direction of Toaldo, who has published several useful works, especially a Treatise on Meteorology, which gained him a prize at the Academy of Montpellier.

At Naples there is an observatory, executed according to the directions of M. Piazzi, of which a plan is given in Plate CCCCXXV. Fig 3 It has stone pillars for supporting the transit, meridian circle, repeating circle, clock, &c. together with convenient apartments for equatorials, telescopes, &c. and is very complete.

In some of the islands of the Mediterranean, observatories have been established.

To Malta, in 1783, the Grand Master, Emmanuel de Rohan, an amateur, and enlightened protector of science, invited the Chevalier d'Angos, a skilful astronomer. He converted a tower of the palace into an observatory, which was furnished with the finest instruments which could be procured. In a few years he made a great number of valuable observations, which he intended to publish; but in March, 1789, the observatory having caught fire, the instruments were destroyed, and the papers burnt; a serious loss to astronomy, particularly as this was the most southern observatory in Europe.

At Palermo, in Sicily, an observatory was constructed in the palace of the Viceroy, under the direction of Father Piazzi, who, in 1787, went to Paris to study astronomy, and afterwards visited England, to consult the principal artists on the proper construction of instruments. In 1789, he returned to Palermo, and added to the apparatus a fine transit instrument, and a complete circle, by Ramsden. His first labours were directed to the formation of a correct catalogue of stars; and, as a foundation, he chose Wollaston's Catalogue, and particularly, as his chief points of reference, Maskelyne's 36 stars. The positions of some of the larger stars he verified by nearly a hundred observations, and, in the prosecution of this task, in 1801, he discovered a new planet, which he named Ceres, in honour of Sicily, as that island was, on account of its fertility, anciently consecrated to the goddess Ceres. This discovery was the more important, as it excited the curiosity and research of other astronomers, by which three more planets have been since discovered.

Observatories in various parts of Europe.

In Hungary, there are observatories at Buda, Tyrnau, and Erlau. There are also similar establishments at Grieffswalde, in Pomerania, and at Mittau in Courland.

In Poland, there is an observatory at Cracow, and another at Wilna. The latter was built and richly endowed by the Countess of Puzynina, a lady of fine genius as well as liberality. It was finished in 1753, and the instruments with which it was furnished were of great variety and value. In 1765, the king of Poland, by letters patent, gave it the title of Royal Observatory, and appointed the learned Jesuit Poczobut, astronomer-royal, who in 1788, added another observatory, which he furnished with new instruments, chiefly made by Ramsden.

In Sweden, observatories have been built at Stockholm and Upsal. That at Stockholm was founded in 1746, by the Academy of Sciences. In 1753, Wargentin was appointed astronomer to it, and, in 1783, he was succeeded by Nicander. This observatory is situated on a hill north of the town, and contains a good collection of instruments, all made by English artists.

The observatory at Upsal was built and endowed in 1739, by the king of Sweden. It was first superintended by the celebrated Celsius, who has been followed by a succession of able astronomers, particularly Hooker and Wargentin. The latter is well known as the author of a set of tables of Jupiter's Satellites. At Dantzic, there was an old observatory, celebrated as having been used by Hevelius, which is fully described in his *Machina Celestis*. A new observatory was built in that city in the year 1778, and superintended by Dr. Wolff.

At Copenhagen, the famous astronomical tower was finished in 1656. It was built by Christian IV. at the recommendation of Longomontanus, and was for many years under the management of M. Bugge, a very able astronomer. He has been succeeded by M. Schumacher, a very distinguished astronomer, and accurate observer, at present at Altona, where, for some years, he has resided for the purpose of carrying on a trigonometrical survey, to be combined with several others of the same kind, instituted in Europe for ascertaining the true figure and magnitude of the earth.

In Holland some attention was paid to practical astronomy while it was a maritime state, but the science has of late been much neglected. In 1690, an observatory was erected for the university; and at Utrecht, an ancient tower was, in 1726, converted into an observatory, where the celebrated Muschenbroek observed for many years with great accuracy, and he was succeeded by M. Hennert.

In Spain, observatories have been built at Madrid, Cadiz, Seville, and Carthagena. The observations made in the Marine Academy at Cadiz, by Miguel and Varilla, have been published in two volumes, which contain also a catalogue of the instruments of the observatory, constructed chiefly by French artists. Of late years, however, English instruments have been introduced.

At Lisbon, in 1728, John V. had an observatory erected at his palace. It was furnished with excellent instruments, and accurate observations have been made there by the Jesuits. They also erected an observatory at their own college of St. Anthony, where Father Carbon, in 1726, made some good observations on the Satellites of Jupiter.

At Lisbon, in 1787, a royal observatory was constructed at the Chateau de St. George, which was superintended by M. Custodio Gomez. At Coimbra, too, there is one which contains a fine equatorial by Troughton.

At Petersburg, an observatory was built in 1725, by Peter the Great, who showed great zeal for science in general and for astronomy in particular. When he was in England, some years previous to that period, he visited the royal observatory at Greenwich, where he examined both the building and the instruments with great attention. The observatory which he built afterwards is one of the most magnificent in Europe. It appears, however, to be too high, being about 130 feet, with three stories, all fitted up for astronomical purposes, in which case the upper stories must be too much agitated in high winds for accurate observations. M. Delisle has made, according to Lalande, a great number of excellent observations here, which are preserved in manuscript at the Marine Depot.

At Moscow, an observatory was built a few years ago, and furnished with some excellent English instruments, chiefly by Cary; but most of them have been destroyed in the late conflagration of that city. We have been informed, however, that a new one is now erecting.—For the plans of the several observatories, see Plates CCCCXXV. &c.

A Table of the Latitudes and Longitudes of some of the Principal Observatories in the World, from the latest and most accurate Observations.

Names of Places.	Latitude.	Longitude.	
		In Degrees.	In Time.
	° ′ ″	° ′ ″	h. m. s.
Amsterdam	52 22 17 N	4 53 15 E.	0 19 33 E
Armagh	54 21 15 N	6 37 30 W.	0 26 30 W
Batavia	6 9 0 S.	106 51 45 E.	7 7 27 E.
Berlin	52 31 45 N	13 22 15 E.	0 53 29 E.
Bologna	44 30 12 N	11 21 30 E.	0 45 26 E.
Bremen	53 4 38 N.	8 48 0 E.	0 35 12 E.
Breslaw	51 6 30 N.	17 2 18 E.	1 8 9 E.
Brunswick	52 16 29 N.	10 32 0 E	0 42 8 E.
Buda	47 29 44 N.	19 2 30 E.	1 16 10 E.
Cadiz	36 32 0 N.	6 17 22 W.	0 25 9 W.
Cambridge (St. M. Steeple)	52 12 43 N.	0 7 34 E.	0 0 30 E.
Cassel	51 19 20 N.	9 35 18 E.	0 38 21 E.
Coimbra	40 12 30 N.	8 24 42 W	0 33 39 W.
Constantinople (St. Sophia)	41 1 27 N.	28 55 15 E.	1 55 41 E.
Copenhagen	55 41 4 N.	12 35 6 E.	0 50 1 E.
Cracow	50 3 38 N.	19 57 9 E.	1 19 49 E.
Dantzic	54 20 48 N.	18 38 5 E.	1 14 32 E.
Dorpat	58 22 47 N.	26 42 0 E.	1 46 48 E.
Dresden	51 2 50 N.	13 43 1 E.	0 54 52 E.
Dublin	53 23 13 N.	6 20 30 W.	0 25 22 W.
Edinburgh	55 57 57 N.	3 10 21 W.	0 12 41 W.
Florence	43 46 41 N.	11 15 45 E.	0 43 3 E.
St. Gall (Switzerland)	47 25 40 N.	9 22 15 E.	0 37 29 E.
Genoa	44 25 0 N.	8 58 0 E.	0 35 52 E.
Glasgow	55 51 32 N.	4 16 0 W.	0 17 4 W
Gotha (Seeberg)	50 56 8 N.	10 44 0 E.	0 42 56 E.
Gottingen	51 31 50 N.	9 56 30 E.	0 39 46 E.
Greenwich	51 28 39 N.	0 0 0	0 0 0
Hyeres	43 7 2 N.	6 7 55 E.	0 24 32 E.
Kew	51 28 37 N.	0 15 45 W.	0 1 3 W.
Leipsic	51 20 16 N.	12 21 45 E.	0 49 27 E.
Leyden	52 9 30 N.	4 29 13 E.	0 17 57 E.
Lilienthal	53 8 30 N	8 54 15 E.	0 35 37 E.
Lisbon	38 42 24 N.	9 8 30 W.	0 36 34 W.
London (St. Paul's)	51 30 49 N.	0 5 47 W.	0 0 23 W.
Madrid (Grand Square)	40 24 57 N.	3 42 15 W.	0 14 49 W.
Malta (Valetta)	35 53 0 N.	14 30 35 E.	0 58 2 E.
Manheim	49 29 18 N	8 28 0 E.	0 33 52 E
Marseilles	43 17 49 N.	5 22 15 E.	0 21 29 E
Milan	45 28 2 N.	9 11 31 E.	0 36 46 E.
Mirepoix	43 5 7 N.	1 52 26 E	0 7 30 E.
Mittau	56 39 6 N.	23 43 27 E.	1 34 54 E.
Montauban	44 0 55 N.	1 20 45 E	0 5 23 E.
Montpellier	43 36 16 N.	3 52 40 E.	0 15 31 E.
Moscow	55 45 45 N	37 33 0 E.	2 30 12 E.
Munich	48 8 20 N.	11 34 40 E	0 46 18 E.
Naples	40 50 15 N.	14 15 45 E.	0 57 3 E.
Nuremberg	49 26 55 N	11 4 15 E.	0 44 17 E.
Oxford	51 45 39 N.	1 15 22 W.	0 5 1 W.
Padua	45 24 2 N.	11 51 32 E.	0 47 26 E.
Palermo	38 6 44 N.	13 22 0 E.	0 53 28 E.
Paris	48 50 14 N	2 20 15 E.	0 9 21 E.
Pekin	39 54 13 N	116 27 45 E.	7 45 51 E.
Petersburg	59 56 23 N.	30 18 45 E	2 1 15 E.
Pisa	43 43 11 N.	10 24 0 E.	0 41 36 E.
Plymouth	50 22 20 N	4 7 16 W.	0 16 29 W.
Portsmouth	50 48 3 N.	1 5 59 W.	0 4 24 W.
Prague	50 5 19 N.	14 25 15 E.	0 57 41 E.
Ratisbon	49 0 53 N	12 4 30 E.	0 48 18 E
Richmond	51 28 8 N.	0 18 45 W.	0 1 15 W
Rome (College)	41 53 54 N.	12 29 47 E.	0 49 59 E.
Slough (Herschel's)	51 30 20 N.	0 36 0 W.	0 2 24 W.
Stockholm	59 20 31 N.	18 3 30 E.	1 12 14 E
Strasbourg	48 35 56 N.	7 44 51 E.	0 30 59 E.
Toulouse	43 35 46 N.	1 26 30 E.	0 5 46 E
Turin	45 4 14 N.	7 40 15 E.	0 30 41 E.
Upsal	59 51 50 N.	17 39 0 E.	1 10 36 E.
Utrecht	52 5 31 N	5 7 16 E.	0 20 29 E.
Venice (St. Mark's)	45 25 32 N.	12 20 59 E.	0 49 24 E.
Verona	45 26 7 N.	11 1 15 E.	0 44 5 E.
Vienna	48 12 40 N.	16 22 45 E.	1 5 31 E
Viviers	44 29 14 N	4 41 0 E.	0 18 44 E
Weimar	50 59 12 N.	11 21 0 E.	0 45 24 E.
Wilna	54 41 2 N.	25 18 0 E	1 41 12 E.

OCHILL Hills. See Clackmannanshire.

OCHOTSK, a station or sea-port town in the circle of the same name, and the government of Irkoutsk, in Asiatic Russia. The town, which is upwards of three miles long, and only from 100 to 300 feet broad, is situated on a long and narrow ridge, stretching between the river Okhota and the sea of Ochotsk. There are about 130 indifferent houses in the town, a church, some magazines, a double row of shops, and a harbour scarcely deserving the name, in which M. de Lesseps counted seven or eight small vessels or galiots, some of which belonged to the government, and others to traders in furs to America.

This town being the channel of trade between Irkoutsk and Kamtschatka, the articles of commerce are conveyed to Yakoutsk down the Lena; thence up the Aldane to its conflux with the Judomay; then up the latter river, and over to Ochotsk by a short land carriage. This journey is performed only in spring, and the goods are carried on pack-horses or by men. East Long. 143° 13′ 45″, and North Lat. 59° 20′ 10″. See La Perouse's *Voyage*, vol. ii.

ODESSA, a sea-port town of Russia in Europe, situated on the Black Sea, in the government of Cherson. It stands between the mouths of the Dniester and the Dnieper, at the south-west corner of the bay of Adschai, and on a declivity in the midst of extensive and productive plains. The streets, which are wide and straight, intersect each other at right angles, and the houses are in general neatly built. There are seven churches, an exchange, a theatre, and near the harbour an admiralty court, a custom-house, and an hospital. The warehouses for salt and salted provisions stand to the north of the town, and the water reservoirs are at some distance to the west. There are here a lyceum, schools for trade and navigation, and also for the instruction of girls.

The harbour of Odessa, formed by two large moles, contains about 300 vessels. It has regular parapets and embrazures for cannon, and is commanded by the citadel on the east side. The barracks stand between the harbour and the town, and the lighthouse has been built on a point on the south side of the bay. Public baths have been erected for the use of the Polish families who come here occasionally for sea-bathing. The chief imports into Odessa are sugar and colonial produce; and the great export is corn, from the Ukraine and the neighbouring countries. Tallow, hides, flax, and timber, are also exported to a small extent. About 800 vessels, of which one-third are British, and one-half Russian, arrive annually. There are breweries and distilleries here, and some manufactures of woollen goods, silk, gunpowder, and soap. In 1804, the population was 15.000, and now amounts to about 36,000. East Long. 30° 45′ 22″. North Lat. 46° 29′ 30″, according to astronomical observation.

ODOMETER, or Waywiser, from *ὁδὸς, a road*, and *μετρειν, to measure*, is an instrument for measuring the length of road travelled by a wheel carriage, from the number of rotations performed by the wheel in a given time.

The construction of such an instrument presents no difficulties, the only point of importance being to register the number of revolutions without error, and count them off with facility and accuracy. The odometer which we think best fitted for this purpose was invented, we believe, by the Rev. Mr. Wollaston, and is represented in Plate CCCCXX. Fig. 1, where ABC is an arm of steel, having the teeth of an endless screw cut on the end AB. The teeth of this screw engage in the teeth of two wheels K, L, the one L lying behind K; both its teeth and its circumference being concealed from view. The wheel K has 100 teeth, and L 101; and therefore, since the same endless screw turns both wheels, it is obvious that when K has performed one complete revolution of 100 teeth, 100 teeth of L will also have passed forward; but as L has 101 teeth, the zero of K will have separated from the zero of L 1 tooth, and will consequently point to 1 on the scale of L. After a second revolution of K, its zero will point to 2 on the scale of L. Hence when the index of K points to 101 on the scale of L, the endless screw ABC will have performed 10,100 revolutions. When the odometer is to be used, the arm ABC may be fixed to the moveable axle of the carriage.

Mr. Hunter, of Thurston, has proposed to apply the odometer to a light iron wheel, for the purpose of measuring roads, hedges, walls, and ditches. This application of it is shown in Fig. 2. where A is a light iron wheel two yards in circumference. It is divided into feet by six spokes, one of which is painted white. The handle B is divided at C like a fork, and embraces each end of the axis of the wheel by its elasticity. There is a hole through the middle of the axis, into which is inserted the end BC of the odometer, which is held fast in its place by the nut C.

The following is the method of using it given by Mr. Hunter. "The wheel K, Fig. 1. shows the number of turns made by the iron wheel A, Fig. 2; and the wheel A is divided into six feet, commencing at the white spoke. It is advisable always to commence with the waywiser set at 0. To do this, unscrew the nut I, and draw out the screw BC, when the brass wheels K and L can both be set at 0, and the screw and nut I replaced. Set the wheel A, Fig. 2, on the ground, with the white spoke undermost, and fix the waywiser into the wheel by means of the nut C, always observing to put it on the left side, as shown in Fig. 2. at E. At any period of measuring, you can tell exactly how far you have gone, and proceed without again setting the waywiser at 0.

Suppose the spoke, No. 2. at the ground, as in the figure, the index M pointing at 26 of K, and the index of K pointing to 78 of L, then the distance measured is 7826 turns of A and 2 feet; and as A measures 2 yards, $7826 \times 2 = 15652$ yards, to which add the 2 feet.

In reading off, particular care must be taken always to read the large figures (viz. those on the wheel L) first, and afterwards to add the small figures, (viz. those on the wheel K,) and if the figures on K amount to less than 10, a 0 must be prefixed, so that K shall always show two figures; for instance, L being at 46, and K at 4, the sum is 4604. The easiest way to guard against error is to read 46, and add the word *hundred*; thus *forty-six hundred and four*, and not *four thousand six hundred and four*. For my own use, I have preferred a wheel measuring 6.6 feet, or $6\frac{6}{10}$, which is exactly the tenth part of an English chain, and my iron wheel is divided into 10 parts; so that all my calculations are in decimals. If the waywiser stands, as before, at 7826, and the spoke No. 2. on the ground, then the measurement is 7826 turns and $\frac{2}{10}$, or 7826.2 turns, equal to 782.62 chains, equal to 78.262 furlongs, which may also be read 78 fur. 2 ch. $6\frac{2}{10}$ turns; so that by using decimals there is no more calculation required than if the wheel measured one yard.

Eight hundred turns of the wheel are a mile. Any person preferring Scotch measure may have the wheel made to measure 7.4 feet."*

OHIO, a state of the United States; bounded by Ohio river or Virginia, south-east; Ohio river or Kentucky, south; Indiana, west; Michigan territory and lake Erie, north; and Pennsylvania, north-east.

Ohio has an interior boundary, on Ohio river, from the mouth of Little Beaver, to that of the Great Miama, 440 miles.

Due north from the mouth of Great Miama, north latitude 39° 07′, to north latitude 41° 35′, - - - - - - - - - - - - - -	170
Thence due east to Lake Erie, - - - -	80
Thence along the south-east shore of Erie,	150
Thence along the western boundary of Pennsylvania, - - - - - - - - - - -	93
Having an outline of	953

Area 40,000 = 25,600,000 acres. North latitude 38° 29′. 41° 59′.

The longest line in the state of Ohio, north-east and south-west, is 300 miles. Its width between Pensacola and Indiana 227 miles.

Though not marked by any of those bold and sublime features which are peculiar only to mountainous countries, Ohio presents some very remarkable traits, which call forth the utmost attention of the statist and philosopher.

In my introductory view, I gave a general outline of this part of the Ohio valley, in order to account for the structure of its exterior. To which remarks we may again recur.

When it is known that the vale in which the Ohio flows is from 300 to 400 feet below the common level of the adjacent country, and when it is also known, that an immense table land extends through the state in nearly a north-east and south-west direction, the origin of the phenomena, which serve to form its physiognomy, is easily traced. The rugged appearance of the Ohio banks in all their extent give an idea of unevenness to the state, which an examination of its interior must correct.

Like all other sections of the United States, Ohio cannot be designated by any general character; and similar to every newly settled part of our country, from the attention of early emigrants being naturally turned towards the best soil, the river alluvion and rich prairie margins have contributed to give too high colouring to descriptions of its lands.

As far as a general view can be adopted, the following may exhibit the great outlines of the state.

Fifty or sixty miles from the Ohio river hilly, and in part very rugged; formed by abrasion of water.

The region in the rear of the hilly is not level, though not rising into hills of any considerable elevation; it is rolling land, and presents features in exact accordance with what must arise from the theory we have adopted. The country becoming more level approaching the interior table land; until finally smoothing into the elevated plain from which the rivers flow into Lake Erie, or into Ohio river.

The third variety is that of the plains, or table land. This natural section contains very various species of soil, from rich river alluvion and prairie to sterile oak barrens and marshes: the latter to considerable extent.

Another remarkable natural section of Ohio lies along Lake Erie. The slope of the country rises gradually from Ohio river towards the sources of Muskingum, and Cuyahoga. On the latter, a sudden and much more inclined depression falls towards the lake. This dividing line, for ridge it cannot be called, does not conform to the bearings of Erie. At the north-east angle of the state its apex is within three miles, whilst towards the sources of Maumee, it has receded above 100 miles from the lake.

A series of falls interrupt every river of Ohio flowing into Erie. Those which flow into Ohio river, except Muskingum, though all are rapid in their descent, none have falls. The small cataract at Muskingum, in Zanesville, is the last water-fall in any stream of magnitude worthy notice, on the north-western slope of the Ohio basin. It may not be irrelevant to remark, that on all the vast extent west from Zanesville to the sources of the Plate and Kansas rivers, and north-west to the sources of Yellow Stone and Missouri rivers, no cataract worthy notice has been discovered. Below the Great Kenhawa, on the south-eastern slope, their occurrence is equally rare. The rapids of Ohio and Muscle shoals, in Tennessee, are the only approaches to falls, and both are merely strong rapids; the latter only obstructing upstream, both admitting down-stream navigation. Indeed exemption from impediments to commercial intercourse may be constantly kept in view, as one of the most felicitous features of the whole Mississippi basin. An exemption found to an equal extent no where else on the globe, except in the basins of the Plate, Amazon, and Oronoco rivers, in South America.

It would be a very interesting solution to determine the relative extent of the various natural sections of Ohio. Such an estimate would be so vague, upon the uncertain data we possess, that no satisfactory result can be obtained. It may be observed that the three sections, hilly, rolling, and level, are nearly of equal extent, or about 13 300 square miles each; and that the whole state is, though unequally so, habitable. The result of the settlement of this state proves its general productiveness.

I have been myself over a large part of the southern and northern frontiers of Ohio, and have every where found the soil favourable to the purposes of agriculture. No part of what is called barrens, or swamps, in Ohio, are so irreclaimable as the sandy shores of the Carolinas and Florida, the sea marshes of Louisiana and Texas; or so unproductive as the interminable pine tracts which reach from the Roanoke to Red river.

In point of position, its local is in many respects favourable; but its advantages are more appropriate to an interior than exterior communication. The quantity of its arable soil will, no doubt, combined as it is by many moral causes, superinduce a very dense population in Ohio; circumstances, however, common to all, will produce in Ohio, Indiana, Illinois, and Michigan, a mass of population by far exceeding that of any other equal continuous extent in the United States.

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* These odometers, complete with one iron wheel, are made by Messrs. Howdens, watchmakers, No. 9, South Bridge, Edinburgh.

The most common mineral productions of Ohio are, coal and iron. Coal is found along the Ohio and Muskingum rivers, and iron ore in various parts of the state. Water impregnated with muriate of soda, common salt, has been found, but not in any quantity to render the manufacture of salt an object of any considerable value.

The staples of this state are numerous and important, consisting of wheat, rye, oats, Indian corn, whiskey, apples, cider, live stock, and salted provisions. The most frequented commercial outlets are, by the Ohio, and Mississippi river, to New-Orleans; by Lake Erie and Detroit river, to Detroit; by lakes Erie and Ontario, and St. Lawrence river, to Montreal; and by land, to Pittsburg, New-York, Philadelphia, and Baltimore.

The seat of government is at Columbus, but by far the largest town in the state, is the city of Cincinnati, containing, at present, above 10,000 inhabitants. Steubenville, Zanesville, Cleaveland, and several others, are flourishing places, containing a population of from 500 to 1000.

The civil and political subdivisions of Ohio are the following, with the result of the census of 1820 annexed.

Counties.	*Inhabitants.*	*Square miles.*	*To square mile.*
Adams,	10,406	400	26
Allen,			
Ashtabula,	7,382	700	10
Athens,	6,338	750	8
Belmont,	20,329	500	40
Brown,	13,356	470	30
Butler,	21,746	480	45
Champaign,	8,479	460	18
Clark,	9,533	400	24
Clermont,	15,820	416	38
Clinton,	8,085	360	22
Columbiana,	22,033	864	25
Coshocton,	7,086	900	6
Crawford,		540	
Cuyahoga,	6,328	468	9
Darke,	3,717	672	5½
Delaware,	7,639	650	12
Fairfield,	16,633	540	30
Fayette,	6,316	450	14
Franklin,	10,292	520	19½
Gallia,	7,098	500	14
Geauga,	7,791	600	13
Greene,	10,529	400	26
Guernsey,	9,292	470	19
Hamilton,	31,764	400	79
Hancock,		578	
Harrison,	14,345	450	31
Henry,		630	
Highland,	12,308	420	30
Hardin,		570	
Hocking,	2,130	432	5
Huron,	6,675	900	7
Jackson,	3,746	490	7½
Jefferson,	18,531	500	37
Knox,	8,326	600	14
Lawrence,	3,499	430	8
Licking,	11,861	700	19
Logan,	3,181	500	6
Madison,	4,799	400	12
Marion,		530	
Medina,	3,082	760	4
Meigs,	4,480	400	11
Miami,	8,851	410	21
Monroe,	4,645	518	9
Montgomery,	15,999	480	33
Morgan,	5,297	500	10½
Muskingum,	17,824	660	27
Paulding,		432	
Perry,	8,429	400	21
Pickaway,	13,149	470	30
Pike,	4,253	400	10
Portage,	10,095	750	13
Preble,	10,237	430	23¾
Putnam,		575	
Richland,	9,169	900	10
Ross,	20,619	650	31
Sandusky,	852	600	6½
Sciota,	5,750	575	10
Seneca,		540	
Shelby,	2,106	418	5
Starke,	12,406	800	15½
Trumbull,	15,546	870	17¾
Tuscarawas,	8,328	680	12
Vanwert,		432	
Union,	1,996	500	34
Warren,	17,837	400	44½
Washington,	10,425	600	17
Wayne,	11,933	720	16¾
Williams,		600	
Wood,	733	750	1
	581,434	38,260	15

Ohio is calculated by Mr. Kilbourn, in his Gazetteer, to contain 40,000 square miles. That calculation is, no doubt, nearly correct: therefore, allowing for water surface, irreclaimable swamps, and other uncultivable tracts, the aggregate of the counties will approach very closely to the real arable land of Ohio.

The counties of Crawford, Hancock, Hardin, Henry, Marion, Paulding, Putnam, Seneca, Vanwert, and Williams, have been formed subsequent to the last census, and, being mostly in the new purchase, remain in great part uninhabited. These counties, taken together, amount to 5427 square miles. The aggregate of the census of 1820 was but little influenced in its amount by the few inhabitants then upon this surface; an area approaching one-seventh part of the superficies of the state. Deducting 5427 square miles from 38,260, leaves 32,833, as the really uninhabited surface of Ohio. The latter area has, therefore, at present, if we make but a moderate allowance for the augmentation since the census was closed, upwards of 18 to the square mile. The uninhabited, or thinly peopled counties, more than equal, in point of fertility of soil, the general aggregate surface of the state, and will consequently admit, at least, an equal density of population, or permit the addition of nearly 100,000 inhabitants to the state.

The progressive population of Ohio is an unmatched phenomenon in the history of colonization. In 1783, the ground now embraced within its limits was one wide waste. In 1790, 3000 civilized inhabitants were only found on its surface. In 1800, they had increased to 42,156. In 1810, the census presented an abstract containing 227,843. In 1820, the state possessed 581,434 inhabitants. It demands a very limited knowledge of the relations of Ohio, its admirable position, its exuberant soil, and above all, the effects which must ensue from opening the western canal of New-York, to foresee an augmentation of people on Ohio more rapid in the next ten years than in any equal antecedent period.

Ohio, in 1820, contained 576,572 white inhabitants, and 4723 free coloured persons. In point of classification, the inhabitants were composed of:

Foreigners not naturalized, - - - - -		3,495
Number of persons engaged in agriculture,		110,921
Ditto do.	manufactures,	18 956
Ditto do.	commerce,	1,459

Ohio became a state of the United States in 1803.

OHIO, a river of the United States. See MISSISSIPpi *basin*, section *Ohio*; and Navigation Inland, from page 325 to 332.

Darby.

OILS. See Chemistry.

OISE, the name of one of the departments of the northern region of France, derived from the river Oise, which waters it, and which joins the Seine, five miles south of Pontoise. It is bounded on the north by the department of the Somme; on the west by the department of the Lower Seine and the Eure; on the south by those of the Seine and Oise, and the Seine and Marne, and on the east by the department of the Aisne. It is 27 French leagues long, and 18 broad, and contains 308 square leagues, or 6082 kilometres. The surface, which consists of plains and eminences, has a soil of different qualities, which is in general fertile. The productions are, corn, wine, hemp, flax, wood, soda, cattle, and mineral waters. The principal towns are,

	Population.
Beauvais	13000
Clermont	1995
Senlis	4312
Compiegne	6359

Beauvais is the capital of the department. Population, 360,086. Acres of wood, 90,500. Contributions in the year 1803. 4 714,895 francs.

OLIBANUM, is the name of a gum-resin, supposed to be the frankincense of the ancients. It is obtained in Persia and Arabia, as well as in India. The quantities imported by the East India Company were—

	Cwt.	Value.	Average per Cwt.
1804	78	714*l.*	9*l.* 2 6
1806	287	1136	3 19 2
1807	617	1902	3 1 6
1808	146	173	1 3 7

18 cwt. are allowed to a ton, and the permanent duty is 1*l.* 10*s.* per cwt. See Chemistry, and Milburn's *Oriental Commerce*, vol. p. i. 139.

OLYMPIADS. See Chronology.

OLYMPIC Games. See Athletæ, and Greece.

OPHIOLOGY.

Reptiles belong to the great division of vertebral animals which have cold blood. They differ in appearance from quadrupeds in the absence of hair, and from birds in being destitute of feathers, and from both in the heart not being quadrilocular, nor the blood warm. They agree with fishes in having their body either naked, or covered with scales—in the temperature of their body corresponding with that of the medium in which they reside—in the brain not filling the cavity of the cranium—and in the cerebellum being destitute of the arbor vitæ. They differ from fishes in the nature of their circulation. In fishes, the whole circulating fluid is poured into a pulmonic heart, consisting of a single auricle and ventricle, through which it is conveyed to the gills. The whole blood, thus ærated, is taken up in the gills by vessels which serve the place of the pulmonary veins in quadrupeds, and which carry the red blood directly to all parts of the body, without the intervention of a systemic auricle or ventricle. In reptiles, on the other hand, the blood collected from different parts of the body is again transmitted through a systemic auricle and ventricle, and a part only of this fluid is conveyed to the lungs or gills. This ærated blood, in returning from the gills or lungs, is either conveyed directly to the branches of the aorta, to mix with the circulating mass, or, after being collected into a separate auricle, enters the common ventricle. The partitions which occur in the common ventricle probably prevent the blood, already ærated, from being again, even in the smallest quantity, returned along with the limited portion to the lungs or gills.

The differences which prevail between reptiles and fishes are not greater than those which characterize the different groups into which the former may be divided. In one group, including the frogs, the heart is of the most simple kind, and possesses only one auricle. In the other, the heart possesses two auricles. Among these the turtles are enveloped in an osseous shield, which is wanting in the lizards and serpents. The lizards are furnished with two or four feet, with which they execute progressive motion, while the serpents are truly apodal.

In the article Herpetology, the characters of three of these groups (viz. the Chelonian, including turtles—the Saurian, including lizards—and the Batracian, including frogs) have been given in considerable detail. The fourth group, containing the serpents, was there omitted, and a reference made to the present article, in which their peculiar structure and classification fall to be illustrated.

CHAP. I.

Anatomy and Physiology of Serpents.

The skin of serpents consists chiefly of a cuticle and corium. The cuticle exhibits considerable differences in thickness, and, as happens to the lizards, is periodically cast off and renewed. The corium is destitute of a villous surface, and intimately connected with the muscular web underneath. The appendices of the skin consist exclusively of scales. These are divided by naturalists into two kinds. The true *scales*, or *squamæ*, are usually produced longitudinally, and pointed or rounded posteriorly. They have, in general, some asperities on the surface. The *shields* or *scutæ* are of much larger dimensions, and produced transversely. In some cases they embrace the whole of the body, forming rings; in other cases a half or a quarter of one side only. They usually present a smooth surface, and occur chiefly on the belly, between the throat and vent. They differ considerably in number in different species, and even in individuals of the same genus, so that the character furnished by their number, should be employed with caution in the discrimination of species. There does not appear to be any well marked secretion from the skin, nor are there many species which have glands from which it could proceed. Between the nose and the eye, indeed, on each side, there is a bag or crumen in some species, not unlike the bags which occupy the same position in some of the ruminating animals. Here, however, there is no appearance of glandular structure yet discovered, and the cuticle with which they are lined appears continuous, and falls off along with that which covers the rest of the body. Dr. Tyson first observed these crumens in the rattlesnake; and Dr. Russel and Sir E. Home have since attended to their structure more particularly. The last of these observers, when considering their use, offers the following remarks: "As amphibious animals, in general, have no glands to supply the skin with moisture from within, but receive it by coming in contact with moist substances, it is possible the bags in the snake may be supplied in that manner, and the more so, as the cuticular lining appears perfect.

"Another peculiarity is remarkable in snakes furnished with the bags described above, namely, an oval cavity, situated between the bag and the eye, the opening into which is within the inner angle of the eye-lid, and directed towards the cornea. In this opening there are two rows of projections, which appear to form an orifice capable of dilatation and contraction. From the situation of these oval cavities they must be considered as reservoirs for a fluid, which is occasionally to be spread over the cornea; and they may be filled by the falling of the dew, or the moisture shaken from the grass through which the snake passes." *Phil. Trans.* 1804, p. 74.

The osseous system of serpents is chiefly characterized by the articulation of the vertebræ, the number of ribs, and the absence of the extremities. The head is connected with the atlas by a single tubercle, having three articular surfaces. The posterior articular surface of each vertebra is in the form of a rounded eminence, which is received into a corresponding depression in the anterior end of the one which follows. There is thus throughout the vertebral column a series of ball and socket joints, admitting a great extent of flexure, in some cases restrained by the spinous or articular processes. The ribs in some species amount to nearly three hundred pairs. The dorsal extremities of the ribs are enlarged with a terminal depression, which receives a rounded protuberance of the vertebræ. Each vertebra, therefore, has a rib on each side, united by a modified ball and socket joint. These ribs are not continued beyond the anus. They embrace a great part of the sides, and terminate in cartilaginous processes united to the scales of the belly. M. Lacepede has remarked in the viper, boa, and rattlesnake, that there are uniformly two ribs and one vertebra corresponding to each shield of the belly. In one small group some of the ribs are united by cartilaginous productions on the belly; and there is even the rudiment of a sternum.

The progressive motion of serpents is executed by the assistance of the ventral scales. The body is raised up into one or more arches, and then suddenly unbent is pushed forwards, the posterior edges of the scales, opposed to the ground at the hinder extremity of the circle, offering sufficient resistance. By thus alternately elevating and unbending the body, serpents move in their characteristic manner, backwards or forwards, with an astonishing degree of rapidity. When at their utmost speed, they appear scarcely to touch the ground. In their more ordinary movements, the ventral plates or scales serve as feet. These scales slide under each other by a kind of *inclusion*, so as to permit the ventral surface to shorten or lengthen at the will of the animal. When some of the foremost scales are pressed on the ground, those behind are brought forward, and in their turn supporting the body, enable the fore part to advance. To assist the scales to do this with greater advantage, they are connected with one another by means of muscular threads and a longitudinal band, and are likewise aided by the peculiar mechanism of the ribs. These last, we have seen, are connected with the ventral scales by a flexible cartilage. They are capable of moving on their vertebral joint either ventrally or dorsally, anteriorly or posteriorly. These motions are aided by the muscles which are inserted into them, and originate in ribs contiguous to those to be moved, and in the vertebræ. The body in general is of a rounded form; but when preparing for progressive motion, the ribs are drawn somewhat dorsally, so as to flatten the scales of the belly, and, by moving anteriorly or posteriorly, give to the scales with which they are connected a corresponding degree of motion. The ribs in this case act as limbs to the scales, which may be compared to feet. This singular use of the ribs of snakes in assisting progressive motion was detected by the acute Tyson, in his admirable anatomical examination of the rattlesnake. *Phil. Trans.* No. 144, copied by Ray into his *Synopsis Animalium*, p. 291; and it was still farther illustrated by Sir Everard Home, in his dissections of the boa constrictor. *Phil. Trans.* 1812, p. 163.

Besides the capabilities of executing progressive motion, many serpents can twist their bodies round the branches of trees, or suffer a considerable portion to hang down. In this attitude, the larger kinds are ready to fall down upon their prey passing beneath, such as deers and antelopes. Such animals are not only retarded by their weight, but incommoded by the foe twisting itself in wreaths round their body, and by contractile efforts crushing it to death.

This method of seizing their prey is confined to the larger kinds. The smaller sorts are able by their mouth and teeth to seize and retain their victims. There is no mastication, the food being swallowed entire. To facilitate the deglutition, the under jaws consist of two bones, as in birds, and, like these animals, they are joined to the cranium by the intervention of a bone similar to the os quadratum. The upper jaw is also loosely connected with the head, and in some species admits of considerable motion at the point of junction. The mouth can thus be opened very wide, and larger animals admitted, than, from the ordinary size of the devourer, one would be led to suppose.

The armature of the mouth is of two kinds; common teeth, and poison fangs. The *common teeth* form a single row on each side in the lower jaw, and usually a double row in the upper. The external row, above, is connected with the maxillary bone; the inner row is supported, as in many fishes, on the palatine bones. These both are subulate and recurved.

The *poison fangs*, vulgarly termed the *sting*, are confined to the upper jaw, and occur on each side towards the extremity. In some the fang is the largest tooth, the foremost in the row, and is followed by several common teeth in the maxillary bone. In others, the maxillary bone is abbreviated, and the deficiency at its proximal end is supplied by a long moveable peduncle destitute of teeth. The large fang is placed in this short maxillary bone, and is followed by a few other teeth of similar form. These fangs are to be viewed as the osseous openings of the ducts from the poison bags which are situated at the base. They contain a tubular cavity from their base, passing through the tooth on its convex side to the apex, which ends in a narrow slit. When the serpent bites an animal, the poison flows from the bag through this slit into the bottom of the wound, where to most advantage it can produce its deleterious effects. Whether this dreadful apparatus of venom is to be considered as connected with the digestive system, as an instrument for conquering the prey, and procuring food, or for defensive purposes, has not been satisfactorily determined. The latter conjecture is the most plausible.

The true structure and mode of formation of the poison fangs, appear to have been first investigated with care by Mr. Smith. He found that the poison tube was formed by a fold on the surface, the edges of which met in the middle, but continued separate at the point and base. The hollow in the middle of the tooth in which the secreting pulp was situated, can easily be traced as unconnected with this tubular external fold. The same observer found several of the common teeth having the rudiments of this external groove. (Mr. Smith *On the Structure of the Poisonous Fangs of Serpents. Phil. Trans.* 1818, p. 471.) It is usually supposed, that upon the first fangs being destroyed, others are developed to supply their place. There is, however, some difficulty in accounting for the manner in which the poison duct, in such cases, can change its course. It is probable, that the grooves in the adjoining common teeth have given rise to the opinion. More accurate observation, however, can alone determine the point.

The poison itself has much the appearance of oil; but in its general properties it resembles gum. Its noxious qualities continue even after it is dried.

From the structure of the fangs, the poison is instilled into the bottom of the wound, and if in any quantity it enters any of the larger vessels, death speedily follows. In other cases, there is previously great pain produced; the part swells and becomes discoloured, and exhibits marked indications of violent local action.

The virulence of the poison depends not only on the species of serpent, but on its condition at the time, and the habit of body of the animal which has received the bite.

The remedies which have been suggested to destroy the influence of the venom after the bite, are numerous, but few of them can be safely relied on. Some recommend making an incision into the part wounded by the fangs, and sucking out the venom and contaminated blood. Others advise the unfortunate patient to compress the part by ligature, and thus, by retarding the circulation, give time for the poison to become diluted and neutralized by the local fluids. These remedies are obviously such as in ordinary cases should be resorted to. On the other hand, some recommend the internal and external use of ammonia, the external application of caustic potash, or of heated turpentine. Many vegetables have likewise been employed as antidotes. The subject, however, though one of great interest, is in some measure unexplored, and can only receive useful illustration from the researches of those who reside in the districts where the larger and more venomous species so frequently prove destructive to human life.

The tongue is usually slender, divided at the extremity, and sheathed at the base. The alimentary canal is short in proportion to the size of the body. The gullet and stomach are capable of great dilatation, to receive the large animals which are swallowed. Digestion takes place slowly. The liver is in general uniform in its appearance, and nearly entire. The gall bladder is present. The spleen is of a lengthened form, and placed at the commencement of the intestines.

The heart possesses two auricles, and one ventricle. The portion of blood transmitted for æration, is returned by a systemic vein to the systemic auricle, from which it passes into the common ventricle, which receives through the other auricle the blood returned from the body.

All serpents breathe air. Though many species can dive, they are compelled to return at intervals to the surface of the water in order to respire. The larynx is too simple and membranaceous, to admit of the existence of voice. A hissing sound, however, can be produced. The trachea is a membranaceous tube, terminating directly in the lungs without the usual bronchial divisions. The lungs are single, in the form of an elongated bag, with large cells on the walls. This bag lies in the cavity of the abdomen.

The kidneys are lengthened and labulated. The ureters terminate usually by a single orifice in the cloaca, in the form of a papilla, directed towards the bag, which may be considered as the bladder of urine. This bladder is formed by a fold of the coats of the intestine: it receives the contents of the ureters unmixed with the fæces.

In this receptacle, the urine frequently becomes inspissated, and is voided in lumps at distant intervals, which have frequently been mistaken for fæces. In its ordinary state, Dr. John Davy, to whom the public is indebted for several valuable observations on the urinary organs of the amphibia, (*Phil. Trans.* 1818, p. 304.) describes it as of a butyraceous consistence, becoming hard, like chalk, by exposure to the air, and consisting of pure uric acid.

The reproductive organs of serpents present few peculiarities. The external organs of the male are double, each short, and surrounded with bristles. These, in the rattlesnake and viper, are bifid, and beset with bristles. They appear in a pouch near the anus. In the female the external openings are double, corresponding with the conditions of the male organs. Impregnation takes place internally. Some species are oviparous, others are ovoviviparous. The young do not undergo any remarkable metamorphosis.

Serpents are found in the greatest numbers, both in reference to species and individuals, in tropical countries. In such regions, likewise, they attain the largest size. Few species are found in the temperate and colder districts. In all cases they seem greatly invigorated by heat, and in its absence speedily sink into a torpid state.

Wherever man takes up his abode, there the serpents have to engage in an unequal combat, which ends in their extirpation. Man not only attacks them in open combat, with the lance, the sword, or the musket, but he falls upon them, when gorged with food, and prepared only for slumber, or when in a lethargic state, in consequence of cold. He likewise drains the marshes where they procure their food, and cuts down the forests to which they were accustomed to retire.

But while man, as their personal foe, wages against them a war of extermination, and thus greatly influences their geographical distribution, he receives powerful support from many of the domestic animals which accompany him in his dispersion over the globe. The hog is not afraid to give battle even to the most venomous, and in general comes off victorious. The goat, likewise, readily devours the smaller kinds of serpents, and hence the Gaelic proverb, "Cleas na gaoi ther githeadh nathrach," like the goat eating the serpent, importing a querulous temper in the midst of plenty. *Statistical Account of Scotland*, vol. xii. p. 449.

When unrestrained by opposition from man, and the physical conditions of their life, serpents are well qualified for extending their geographical limits. Neither forest, mountain, marsh, nor rivulet, can retard their progress. Almost all the species can swim, and many of them with the greatest ease. Indeed it is probable that many of those stories which have been propagated regarding *vast sea snakes*, have originated in the appearance of some of the larger serpents at sea, where they have been driven by accident. Some of the Asiatic species reside almost constantly in the waters, either fresh or salt.

Independent of the claim which serpents have to our notice, as constituting an extensive division of the animal kingdom, they furnish an interesting subject of inquiry, from the superstitious opinions which have been entertained concerning them, and the strange properties with which credulity has invested them. It is not our province to give a history of the errors of the human mind, when untutored by that philosophy which gives precedence to accurate observation, but to unfold those characters which the different species exhibit, and by which they may be recognized. In this inquiry it is indeed painful to consider, that human ingenuity has hitherto failed to convert serpents into any thing that is useful; for it is not worth while to regard them in this light, when occasionally furnishing a repast to a few naked savages, or serving to amuse, when dancing to the signals of a juggler, before a few indolent Asiatics. It is still more painful to consider the destruction of human life by their venomous fangs, or the quantity of misery which they have occasioned to those who have survived the noxious bite.

Having made these preliminary observations on the peculiarities of structure of serpents, as constituting a natural division in the class REPTILES, we shall now proceed to give a brief exposition of the characters by which they are distributed into subordinate groups, enumerating all the genera, and taking notice of at least one species belonging to each.

CHAP. II.

CLASSIFICATION OF REPTILES.

Serpents admit of a very natural distribution into two sections, according as the scales on the belly are similar or dissimilar to those on the back. Other characters, correlative with these, intimate the propriety of the arrangement.

DIVISION I.

Serpents with the Ventral and Dorsal Scales similar.

The serpents of this division which are destitute of ventral shields have the lower jaws intimately united, and supported at the base by two ossa quadrata, which are articulated immediately to the cranium. The upper maxillary bones are united to the cranium and to the intermaxillaries. This arrangement limits the power of gaping or of swallowing objects larger than the ordinary aperture of the mouth. The body is nearly of equal thickness at both extremities. Progressive motion is chiefly accomplished by unbending the arches into which the body is successively thrown. The body can advance or retreat by either extremity, with nearly equal readiness. The eyes are so small, that with many they have passed unobserved.

SUBDIVISION I.

Serpents with a Third Eyelid.

In the animals of this group the teeth are small and nearly of equal size. The tongue is notched in a crescent form. The ribs are more or less united to supply the place of a sternum. When irritated, the body is thrown by the muscles into a very rigid state, in which condition it breaks into fragments by the slightest stroke. None of the species are considered venomous. The condition of the rudiments of some of these organs, possessed by the Saurian reptiles, which may here be detected, justify the subdivision of the three genera here contemplated.

SECTION I.

Traces of scapular and clavicular bones occur under the skin. There is likewise a minute sternum and an imperfect pelvis. Though the rudiments of the extremities can be detected within the skin, there are no vestiges of legs or feet on the outside.

GENUS I. OPHISAURUS.

The tympanum is externally visible. The maxillary teeth are conical, and besides these there are two groups on the palate.

Sp. 1. *Ophisaurus ventralis.* This is the Anguis ventralis of Linnæus. It inhabits the United States. The tail is longer than the body, to which it is joined by a hollow circular furrow. On account of its brittleness, it is termed by Catesby the glass snake.

GENUS II. ANGUIS SNAKE.

The tympanum is concealed. No palatine teeth. The maxillary teeth are compressed and recurved.

Species 1. *Anguis fragilis.* Blind-worm. This species is ovoviviparous. It feeds on beetles, mice, and frogs. It resides in holes near woods and heaps of rubbish. It varies considerably in its colour markings. In its young state it has been regarded as a distinct species, under the title *Anguis erix*, or Aberdeen snake.

SECTION II.

No vestiges internally of pelvis, scapula, clavicle, nor sternum; the anterior ribs, however, are united by intervening cartilaginous productions, which serve instead of a sternum.

GENUS III. ACONTIAS.

The teeth are conical. There is the rudiment of a second lobe of the lungs.

Sp. 1. *Acontias meleagris*—the Anguis meleagris of Linnæus. It is a native of India. In the distribution of the colours on the body, it resembles the Guinea-fowl. Hence the origin of its trivial name.

SUBDIVISION II.

Serpents Destitute of a Third Eyelid.

The serpents of this division are likewise destitute of all vestiges of sternum, pelvis, or shoulder bones, neither do the ribs unite to complete the circle.

SECTION I.

Body covered with scales.

1. Scales in rings.

GENUS IV. AMPHISBÆNA.

Scales quadrangular, and disposed in circular bands round the body. Before the vent there is a row of perforated tubercles, the openings of excretory ducts. Oviparous.

Sp. 1. *Amphisbæna fuliginosa.* This species inhabits India, is of a sooty black colour, and rarely exceeds two feet in length.

2. Scales imbricated.

GENUS V. TYPHLOPS.

Scales small, and placed in an imbricated order. Snout depressed and produced; tongue long and forked.

Sp. 1. *Typhlops lumbricalis.* This is the Anguis lumbricalis of Linnæus. It is a native of the West Indies and America. The vent is near the extremity, which terminates in a hard-pointed scale.

GENUS VI. TORTRIX.

Ventral scales slightly enlarged; tongue thick and short.

Sp. 1. *Tortrix scytale.* This species, formerly included in the Genus ANGUIS, has three large scales on the head. It inhabits America.

SECTION II.

Body uniformly covered with tubercles.

GENUS VII. ACROCHORDUS.

The tubercles may be viewed as modifications of scales; they have each three ridges; the top of the head is flat, and covered by small imbricated scales.

Sp. 1. *Acrochordus Javanensis.* This singular snake was found by Mr. Hornstedt in the Island of Java. It is ovoviviparous.

DIVISION II.

Serpents with the Ventral and Dorsal Scales dissimilar.

The ventral scales of this division constitute those shields or scutæ which have been already described. The lower jaw bones are loosely connected; and the ossa quadrata have a free motion on the skull, or are supported on cartilaginous or osseous peduncles. The upper maxillaries are likewise loosely connected with the skull and the intermaxillary bones. This condition of the jaws increases greatly the power of gaping, and enables the serpent to take into the mouth animals much larger than the ordinary thickness of the body. The palatine bones are likewise loosely connected, and armed with recurved pointed teeth.

SUBDIVISION I.

Destitute of Poison Fangs.

The serpents of this division, like those of the preceding, are not venomous. There are four regular rows of entire teeth above, and two below.

SECTION I.

Shields under the tail simple, like those on the belly.

GENUS VIII. ERPETON.

This genus, instituted by Lacepede, is characterized by two soft eminences, covered with scales, seated on the extremity of the snout. The shields under the tail are small. Head with large plates.

Sp. 1. *Erpeton tentaculatus.*

GENUS IX. BOA.

Snout destitute of soft eminences. Vent furnished with a hook on each side.

Sp. 1. *Boa constrictor.* This is the largest species of serpent. It is upwards of twenty feet in length, or, according to some travellers, it even exceeds double that length. It is capable of swallowing deer, goats, and men, entire. When resistance is offered by its prey, it crushes it to death by embracing it in the wreaths of its body. By thus crushing the bones, it is able to reduce a buffalo to such a soft state as to be swallowed whole. It suspends itself from the branches of trees by means of its prehensile tail, and in this manner is prepared to drop upon any animal passing beneath. Sometimes it fixes itself by the tail to a tree, and suffers its body to float in the stream at those places where oxen and other animals come to drink, which it then seizes in its fatal embrace. Whether we consider the great extent of gape and dilatable gullet, and consequent power of swallowing, the enormous crushing force which it can exert when twisted round its prey, its courage, or its locomotive powers, being capable of climbing trees and suspending itself from the branches, or entering rivers, lakes, and the sea, and swimming with great celerity, we have reason to regard it as one of the most formidable monsters of the equatorial regions. To attack it when in an active state would be madness; but, when gorged with food, the victory is easy. The absence of poison fangs, however, prevents it from inspiring so much dread as the larger venomous kinds.

SECTION II.

Shields under the tail divided, or forming a double row.

GENUS X. COLUBER. (PYTHON of *Daudin.*)

Vent furnished with lateral hooks like the Boa. The ventral shields are narrow.

Sp. Coluber Javenensis. This species sometimes exceeds thirty feet in length.

Several genera have been contemplated which are nearly related to Python, as the *Hurria* of Daudin, in which the shields under the tail are only in a double row towards the extremity; and the *Dipsas* of Laurenti, in which there is a row of larger scales on the ridge of the back. The body is compressed.

GENUS XI. NATRIX.

Destitute of anal hooks. Oviparous.

Sp. 1. *Natrix torquata.* Ringed snake. This harmless species is a native of Britain. It frequents moist ground; is easily tamed, and feeds on frogs, mice, and small birds. It is oviparous, and usually deposits its eggs, which are united in a cluster by a gluey matter, in dunghills: they seldom exceed twenty in number.

SUBDIVISION II.

Furnished with Poison Fangs.

SECTION I.

Poison fangs single, followed by a row of common maxillary teeth. These last are not so numerous as in the harmless kinds of the preceding section.

1. Body behind, and tail rounded.

GENUS XII. PSEUDOBOA.

Shields of the belly and lower side of the tail single. Head covered with large plates. A swelling at the occiput. Back carinated, and covered with a row of enlarged scales.

Sp. Pseudoboa fasciata. This species inhabits India, and sometimes attains to eight feet in length.

GENUS XIV. TRIMERESURA.

Shields under the tail near the vent single, but towards the extremity double. Dorsal scales not enlarged.

Sp. 1. *Trimeresura viridis.* This species and the others of the genus which are known, are natives of India.

2. Body behind, and tail much compressed. This form enables the species to swim with ease. They frequent arms of the sea, lakes, and rivers. Head covered with large plates.

GENUS XV. PELAMIS.

Hind head swollen. Scales rather reticulated than imbricated. Ventral shields minute.

Sp. 1. *Pelamis bicolor.* A native of the South Sea Islands.

GENUS XVI. HYDROPHUS.

Head not swollen. The shields are more distinct than in Pelamis.

Sp. 1. *Hydrophis aysfesurus.* From the Indian seas.

To this division of water serpents M. Cuvier (*Regne Animal*, ii. p. 75) has added a genus Chersydrus, containing the *Acrochordus fasciatus* of Shaw. The head is destitute of large plates, and the scales on the body are minute.

SECTION II.

Upper maxillary bones destitute of common teeth, supporting only the poison fangs on each side.

1. *Tribe.*—The shields entire on the belly, and under the tail beyond the vent.

A. The entire shields under the tail continued to the extremity.

Tail furnished with a rattle. (*crepitaculum.*)

This very remarkable organ occurs as an appendage to the tail, the last vertebra of which is enlarged to serve as a mould for its production. This vertebra is somewhat conical, rounded at the extremity, subquadrangular, with three rounded circular ridges, the largest of which is next the body. The first formed cup of the rattle, which in substance is similar to the scales, exhibits the form of the vertebra, from which however it is separated by a thin membrane. It is connected directly with the scales on the back, and, by the intervention of a row of small scales, with the shields on the belly. Thus formed, the cup has three ridges externally, with corresponding grooves internally.

When this first cup has arrived at maturity, a second begins to form underneath. The terminal and middle ridges of the second grow within the grooves of the middle and basilar ridges of the first. As these ridges of the second increase in size, they push from the vertebra the first formed joint, and the second cup appears, with its basilar ridge only visible externally; its middle and terminal ones being covered by the basilar and middle regions of the first. In this manner are the rattles formed, to the number of twelve, or, if certain relations are to be credited, to the number of twenty or even thirty cups.

As the middle and terminal ridges of the last formed cup are rather less in diameter than the grooves of the basilar and middle ridges of the preceding one in which they are contained, a kind of ball and socket joint is formed at each division, admitting an imperfect degree of motion when the body moves.

Each cup, when covering the vertebra, appears to be nourished in the same manner as the skin. When detached from the vertebra, however, though still connected with the last formed one, it dries, and becomes brittle and elastic. When the serpent moves its body, the cups of the rattle, likewise moving upon one another, make a noise not unlike the folding of dried parchment. This noise is said to be audible at the distance of twenty yards, and is thus useful in giving warning of the approach of the destructive reptile to which it is attached. As the cups of the rattle consist merely of dried matter, which in the dry season is brought into a condition to make a noise when the animal moves, so in like manner, under the influence of external circumstances, the rattle in the wet season is soft and mute.

It does not appear to be as yet determined, whether a new cup is formed with each renewal of the skin, or whether the succession of the cups takes place in a different order. The number of cups found in a rattle can scarcely be considered as the number which have actually been formed, but merely as the number of those which have outlived accidents.

There are two nasal bags or crumens, and two scent bags at the vent.

GENUS XVII. CAUDISONA. *Rattlesnake.*

The head in this genus, (the title of which is derived from the old trivial name of the most remarkable species,) is covered with scales similar to those on the back.

Sp. 1. *Caudisona horrida.* Boguira. This species is distinguished by its dark-coloured transverse bands. In size it exceeds four feet in length, and even according to some travellers it reaches to nine feet. It inhabits the extensive forests of America, and feeds on birds and squirrels, and other small animals. Its bite is so dangerous as to produce death, in some cases, in a few minutes. This snake, however, seldom bites unless when irritated; the noise of its rattle gives warning of its approach, and its fœtid odour is readily perceived by horses and oxen.

Sp. 2. *Caudisona durissa.* Durissus. This species is characterized by its dark longitudinal dorsal lines and rhomboidal spots.

Genus XVIII. Crotalus. Millet.

Head covered with large plates.

Sp. 1. *Crotalus miliaris.* This species inhabits Carolina.

Tail destitute of a Rattle.

Genus XIX. Scytalus.

Destitute of nasal bags.

The species of this genus, natives of India, are but imperfectly known.

B. The entire shields under the tail not continued to the extremity.

Genus XX. Acanthophis.

Shields double towards the extremity of the tail, which terminates in a spinous process.

There are two species, *Acanthophis palbebrosus* and *Acanthophis Brownii.*

Genus XXI. Langaia.

Shields behind the vent, forming rings, which surround the body. The under side of the tail, towards the extremity, covered with small scales. Snout produced.

Sp. 1. *Langaia nasuta.* The head is covered with large plates. This species, the only one known of the genus, is a native of Madagascar.

I. *Tribe.*—Shields behind the vent divided.

A Tail round.

(1.) Head behind larger than the neck.

Head furnished with crumens.

Genus XXII. Trigonocephalus.

Head much enlarged behind. Tail frequently armed with a spinous process.

Sp. 1. *Trigonocephalus lanceolatus.* The head of this species, from the eyes to the nose, is subtriangular. The body is usually of a yellow colour. The length sometimes reaches to six feet, and the diameter to three inches. The female is ovoviviparous, the period of gestation six months, and the number of young from twenty to sixty.

This species is frequent in Martinique, frequenting the plantations of the sugar-cane. Its bite is exceedingly dangerous, and much dreaded. The animal, however, seldom attacks a man unless previously irritated.

There are many other species belonging to this genus, which may afterwards be raised to the rank of genera, and which may be distinguished by the arrangement of the scales on the head, and those at the extremity of the tail.

Destitute of crumens.

(a.) Hind-head furnished with a hood.

Genus XXIII. Naja.

Head covered with large plates.

Sp. 1. *Naja lutescens.** This species is a native of India. It is between three and four feet long, fierce, and exceedingly venomous. The jugglers, however, have frequently succeeded in taming it. There are several other species, inhabitants of South America.

(b.) Hind head destitute of a hood.

(aa.) Furnished with cuticular appendices on the forehead.

Genus XXIV. Cerastes.

Scales on the head similar to those on the back.

Sp. 1. *Cerastes vulgaris.* This species carries a small corneous, quadrangular, pyramidal process immediately above each eye. These processes are connected with the skin merely, consist of different layers, and are covered at the base with minute scales.

Sp. 2. *Cerastes Ammodytes.* On the point of the snout there is a soft moveable process, covered with small scales, and two tubercular processes at each nostril. This species seems to be the type of a new genus.

(bb.) Forehead destitute of appendices.

1. Head covered with small plates.

Genus XXV. Chesrœa. Aesping.

Head covered in the middle with three plates.

Sp. 1. *Chersea vulgaris.* The scales on the back have each a longitudinal ridge. There is usually a heart-shaped mark on the crown. The colour is reddish, but subject to vary. By some, the Black Adder, (Coluber Prester) is regarded as a variety of this species, while others refer it, along with the chersea, to the Vipera berus.

This species inhabits Sweden, and is reckoned exceedingly venomous. It appears probable, from the observations of the Rev. Thomas Racket, (*Linnean Transactions*, vol. xii. p. 349,) that it is a native of Dorsetshire, and there known under the name of the red viper.

Genus XXVI. Hemachatus.

Head covered with four rows of large plates.

Sp. 1. *Hemachatus vulgaris.* This species, first figured and described by Seba, is a native of Persia and Japan. The scales on the back are smooth.

2. Head covered with common scales.

Genus XXVII. Cobra.

Scales on the head carinated. The head itself, from the eyes to the snout, subtriangular.

Sp. 1. *Cobra atropos.* The general colour is whitish, with four rows of brown spots, each with a white dot in the centre. Inhabits America.

Genus XXVIII. Vipera. Viper.

Scales on the head rough.

Sp. 1. *Vipera berus.* Common Viper, or Adder. The usual length is about two feet. The colour is greyish, with a chain of irregularly shaped spots along the back. The scales on the back are furnished with a long medial ridge.

The viper is ovoviviparous, and brings forth from twelve to twenty young ones at a birth. It feeds on insects, lizards, and frogs, and is capable of surviving a long time without food. It is found widely dispersed throughout the different countries of the old world.

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* When the animals of this group are irritated, the skin on the neck is extended and drawn forwards, and appears behind the head as a kind of hood. This motion is produced by the cuticular muscles of the neck, aided by the moveable ribs. This mechanism, as displayed in the common Cobra di capello, is exhibited by Sir Everard Home, in his "Lectures on Comparative Anatomy," vol. ii. Tab. ii. iii. iv.

This species is subject to considerable variation in its colour markings, a circumstance which has given rise to the establishment of several spurious species. The coluber cœruleus of Sheppard (*Linnean Transactions*, vol. vii. p. 56.) does not possess any marks of sufficient importance to distinguish it from the common viper.

(II.) Head, behind, of the same size as the neck.

This uncommon narrowness of the head arises from the shortness of the os quadratum, and the osseous peduncle, by which it is united with the skull. The power of swallowing large objects, is consequently limited, as the jaws have but little motion.

Genus XXIX. Elaps.

Head covered with large plates.

Sp. 1. *Elaps lacteus.* Milky viper. The general colour is white, beautifully marked with bright black spots arranged in pairs. The head is black, with a narrow white stripe from the snout to the neck.

B. Tail compressed.

Genus XXX. Platurus.

Head covered with large plates.

Sp. 1. *Platurus laticaudatus.* The tail is thin, like the blade of a knife. The extremity is blunt, and terminates in two round scales. This is an aquatic species, and is found in the Indian seas.

Serpents require little preparation for a museum. They may be skinned by first making a small opening at the side, and turning back the skin both ways to the head and tail, taking out the contents of the body, and filling the skin again with tow or straw. The brain and eyes are extracted in the same manner as is practised in preparing quadrupeds or birds. In general, however, when the specimens are of a small size, it is advisable to keep them in spirits.

Description of Plate CCCCXXVII. connected with this article. Fig. 1. Cerastes vulgaris. Fig. 2. Trigonocephalus lanceolatus, exhibiting the long forked tongue, the poison fangs, and the entry to left cumen between the nostril and eye, of a venomous serpent. Fig. 3. A poison fang of the Naja lutescens, or Cobra di capello, a little magnified, exhibiting the lateral fold or tube for the conveyance of the poison, and a section of the same tooth near the base. Fig. 4. 8. The rattle of the Caudisona horrida, with one of the joints separated. 5. The stomach, with part of the gullet and duodenum of the common viper. 6. Two vertebræ and a rib of the Boa constrictor, illustrating the articulation of the spine and ribs. (J F.)

OPIUM, is the name given to the inspissated juice of the white poppy. In our articles Chemistry, and Materia Medica, we have already given an account of the method of preparing opium, and of its chemical and medical properties. The following Table shows the quantities imported into England, the quantities exported, and the quantity consumed, from 1786 to 1801.

Years.	Imports.		Total.	Export.	Home Consumption.
	Bengal.	Europe.			
	lbs.	lbs.	lbs.	lbs.	lbs.
1786	750	7,702	7,752	1,217	6,537
1787	. .	5,873	5.873	1,655	4.218
1788	. .	4,692	4,692	1,685	3,007
1789	. .	13.923	13.923	377	13,546
1790	1,500	6,389	7.889	1,237	6,652
1791	. .	9,073	9,073	1,104	7,969
1792	2,100	19 683	21,783	7,775	14,008
1793	1,554	32,008	33,562	1,261	32,301
1794	. .	14 857	14,857	1,413	13,444
1795	. .	2,083	2,083	999	1 084
1796	8,164	12,527	20,691	859	19,832
1797	1,522	5,661	7,183	2,371	4.812
1798	395	9 310	9,525	1.237	8,288
1799	7,295	17,153	24,448	3.229	21,219
1800	19,190	29,492	48.682	1,874	46,808
1801	14,951	39,304	54,255	10,361	43,894

In the year 1809-10, the revenue which the Bengal government derived from the sale of opium was 580,000*l*. The opium shipped from Bengal in the year 1805-6 had the following value, and was sent to the following places.

	Sicca Rupees.
China	3.294 570
Penang, and eastward . .	2,125,209
Coast of Sumatra . . .	320,748
Manilla	27.661
Coast of Coromandel . .	61,968
Pegu	15,110
Arabian and Persian Gulf .	1,755
Coast of Malabar . . .	15,515

In the year 1809, 1991 lbs. of opium sold at the East India Company's sale in England for 2249*l*.

A very interesting account of the preparation of opium in Scotland, by Mr. Young, will be found in the *Edinburgh Philosophical Journal*, vol. i. p. 258. 427. See also Kæmpfer's *Amænitates Exoticæ*, fasc. 3 obs. 15. Millburn's *Oriental Commerce*, vol. i p 219. Dr. Crump's *Inquiry into the Nature and Properties of Opium*. *Parliamentary Reports*, vol. vii. p. 23. Kerr's *Medical Observations and Inquiries*, vol. v. p. 28. *Transactions of the Society of Arts*, vol. xvi. p. 273. Desrosnes, *Ann. de Chim.* lxv p. 270. 279.

OPOPONAX, the name of an inspissated vegetable juice, which has been already described in our article Chemistry. The purest opoponax is in grains, from the size of a pin's head to that of a pea. The clear pieces are the best, and those that are black and hard should be rejected. This is esteemed one of the most valuable gums, and is obtained chiefly from Turkey. The price of it is from 36*l* to 40*l*. per cwt. The permanent duty is 2*s*. 3*d*. per pound. Specific gravity, 1.622.

OPORTO, a city of Portugal, in the province of Entre-Douro-é-Minho. It is situated about two miles from the mouth of the river Douro, and on its north bank. The town is chiefly built on a steep hill, which rises very abruptly from the bank of the river, and at some distance presents a very striking and romantic appearance. The houses being white-washed, give it an appearance of excessive cleanliness; but, on a closer inspection, many of the streets are found to be narrow and very dirty; some, however, are wide and airy, exhibiting many new and handsome houses. In one of the principal streets is situated the English factory-house, a large handsome building, erected about twenty years ago, in which the British consul has his office, and in which are also a library and reading room, and a spacious ball room. Many of the houses have gardens attached to them, and these hanging among the rocks, and filled with orange trees and vines, add much to the beauty of the city. The steep declivity of the hill, on which the city is built, renders walking and riding on horseback or in carriages more laborious than in Lisbon. On the east side of the town are houses built against so steep a part of the declivity over the stream, that they can only be entered by steps cut out of the rock. This inconvenience is indeed compensated, at least to a stranger, by the romantic prospect they enjoy of the finest part of the opposite bank, with its towns, villages, monasteries, and pine woods.

To the westward, along the declivity of the hill, are a number of detached houses, forming the market town of Gaya, a place remarkable both for its situation and name. Here, in former times, a place called *Cale*, of which the ancients speak, is said to have stood; but Oporto being afterwards built, or being more convenient for ships, from the greater depth of the water along the bank, it was called *Portus Cale*, or the harbour of Cale, whence was derived *Portucal*, and at last *Portugal*. Portus Cale was at length called O Porto, (*the Harbour*) which name the town of Oporto afterwards received. Advancing to the eastward, and closely connected with the former, is the town called Villa Nova do Porto, chiefly inhabited by wine coopers, and others employed by the wine merchants of Oporto, in their immense magazines or lodges, as they are called there, where all the wine is kept from the period of its being brought down the Douro until it is exported. These magazines are all situated in that village, between which and Oporto there is a communication across the river by a bridge of boats, the expense of which is defrayed by each person paying a small copper coin as he passes and repasses. These boats are removed during a few weeks in spring, when the river is swollen from the rains, and the melting of the snow in the mountains of Spain, which is there called a *fresh*, and by which the water rises sometimes to a very great height. In 1820 it rose eighteen feet, and did much damage to the shipping then in the river. On a rocky eminence, near Villa Nova, is a monastery and its beautiful quinta, near which the British crossed the Douro in the peninsular war, under a tremendous fire from batteries erected by the French on the north side.

Oporto contains four suburbs, seven parishes, ten churches, twelve convents, and nine hospitals; a theatre, and a kind of circus, which is a handsome building. It is partly surrounded by an old wall, five or six feet thick, flanked at intervals with mean-looking towers. The quay, which is of a simple construction, extends the whole length of the town. On one side of it is a street, and the other side of it is walled and raised, though merely for the purpose of making ships' cables fast.

The harbour of Oporto, formed by the river, is difficult of entrance, from rocks rising out of the sand, though it is spacious and secure. "In front of the town the river is very deep. Two masted vessels can come to the town itself; those with three masts within a quarter of a league; and the great Brazil ships alone unload their cargoes in the road. The principal article of commerce of Oporto, is white and red wine, but particularly port wine, which is made in the province of Tralos Montes, to the north-west, and in some districts of Entre-Douro-é-Minho to the north. The quantity annually exported is about 40,000 pipes, which goes almost wholly to England. The other articles of export are, oil of inferior quality, shumac, lemons, and oranges, and some colonial produce. The imports are flax, iron, cod-fish, rice, wheat, and goods of British manufacture. There are at Oporto some manufactories of hats, silks, linen stuffs, and pottery; and there are some rope-walks and dock-yards. Previous to 1790, 500 ships entered Oporto annually; and in that year, the imports amounted to 600,000*l*. and the exports to 800,000*l*. In 1789, nine millions of oranges were exported from Oporto alone.

In 1796, the following ships entered and sailed out of Oporto.

	Entered.	Cleared out.
Americans . . .	10	6
Bremen	2	2
Danish	51	52
Spanish	2	2
Hamburghers . . .	36	34
English	88	99
Lubeck	4	4
Portuguese . . .	35	42
Prussians	27	26
Papenburg	1	1
Swedish	32	29
	288	297

The harbour of Oporto has been gradually filling up by the sand washed down by the river. Endeavours, however, have been made to keep the stream in one place, so as to wash the sand away. The entrance to the harbour is defended by a small fort, San Jaoa de Fez, near which is a small market town. Besides this, there is on the coast, to the north, a harbour; on the beach opposite to which, on the south side, is also a very small fort, called Santa Caterina, with a few other batteries.

There is a very agreeable walk up the river, which forms a principal object to the right; and to the left is a steep rocky declivity, on an eminence opposite to which is a monastery with its woody quinta. The country at a greater distance is very beautiful, and forms cheerful hills. Another walk of the same kind accompanies the river down to the sea.

In winter, the climate of Oporto is damp and foggy; and though the air is cool, yet it seldom freezes. In the summer the heat is very great. The gardens round Oporto are beautiful and pleasant, and the plants of the Cape and of New Holland grow in the open air. Population about 70,000, East Long. 8° 36′ 9″. North Lat. 41° 8′ 56″. See Link's *Travels in Portugal*, p. 320; and *Descripcao Topografica e Historica da cidade do Porto, por* Agostinho Rebello da Costa. Porto, 1789.

OPTICS.

The term Optics, derived from the Greek word *ωπτομαι*, *I see*, is that branch of natural philosophy which treats of the nature and properties of light, and of the changes which it experiences, either in its qualities or in its direction, when transmitted through bodies either natural or artificial;—when reflected from their surfaces;—or when passing by them at a small distance.

History.

Although history has not handed down to us the early speculations of philosophers respecting some of the more striking phenomena of optics, yet there can be no doubt that they must have been observed and studied in the earliest periods of civilization. If the nature of light and colours, and the general phenomena of vision, were subjects too profound for their investigation, they could not fail to acquire some knowledge of the reflexion of light, and the formation of reflected images. Even the rudest savage must have observed with wonder the inverted picture of himself or of his companion, formed by the surface of the water; and in the reflected landscape, or in the image of a few bushes on the margin of a lake, the humblest inquirer might have found an assemblage of experiments, from which the general law of reflexion might be easily inferred.

Metallic mirrors, however, seem to have been in general use, and glass itself manufactured, long before any of the speculations of the ancients were recorded. Mirrors of metal are distinctly mentioned in the books of Job and Exodus; and Pliny informs us, that glass was accidentally discovered by the dealers in nitre who traversed Phœnicia. Being desirous of cooking their food on the banks of the river Belus, and having no stones to support their tripods, they substituted pieces of nitre; and found, to their great surprise, that the matter of the tripods incorporated itself with the nitre, and formed small streams of a transparent matter, which cooled into glass.

The invention of burning lenses of glass seems to have speedily followed the discovery of the art of glass-making. In the second act of Aristophanes' comedy of the Clouds, which was performed in the year 424, B. C. burning lenses are mentioned in the most unequivocal manner; and Strepsiades remarks to Socrates, that he has no doubt seen, in the hands of the druggists, the fine transparent stone with which they light the fire. Socrates asks him, if it is glass that he speaks of, and Strepsiades, replying in the affirmative, adds, that by holding this stone to the fire, he could, at a distance, melt any writing of assignation,[*] and thus free himself from his debts.

One of the earliest optical speculations related to the visibility of objects. Pythagoras maintained that objects were seen by particles continually emitted from the surfaces of bodies, and entering the pupil of the eye, while Empedocles and Plato supposed that vision was effected by something which was emitted from the eye, and which, after meeting with something emitted from the object, was reflected back to the organ of sight. Notwithstanding the absurdity of the Platonic doctrine of *ocular beams*, as they were called, the followers of Plato were acquainted with two very important and fundamental points in the science. They taught that light, from whatever source it was emitted, *was propagated in straight lines*, and that, when it was reflected from the surface of polished bodies, *the angle of reflexion was equal to the angle of incidence.*

Although Aristotle reasoned very superficially in his attempt to establish the incorporeal nature of light,—to discover the cause of transparency,—and to explain the bent appearance of a stick held obliquely in the water; yet he is entitled to considerable credit for his sagacious though vague speculations respecting various optical phenomena. He ascribed the imperfect darkness which exists where the rays of the sun do not shine, to the reflection of light by the atmosphere. He observed pretty accurately the general phenomena of rainbows, halos and parhelia; and he ascribed the rainbow to the reflection of the sun's rays, from the drops of rain, which produced an imperfect image of his disk.

There can be little doubt but that the ancients were at a very early period acquainted with the use of lenses and mirrors, for the purpose of burning bodies placed in their focus. It is probable that the Romans lighted their sacred fires by the aid of concave reflectors; and notwithstanding the objections which have been urged against the burning apparatus of Archimedes, there is every reason to believe that the Syracusan philosopher destroyed the Roman fleet by means of the heat reflected from a number of plain mirrors. See our article Burning Instruments, where this subject has been fully discussed.

The earliest writer on optics was the celebrated Euclid, who drew up a complete treatise on the subject, which has been handed down to us along with his geometrical works.[†] This treatise, which consists of two books, one on optics, containing 60 theorems, and the other on catoptrics, containing 31 theorems, relates to the determination of the apparent magnitude and form of objects from the angle under which they appear, and the apparent place of the images of objects reflected from polished mirrors. In the first part, Euclid endeavours to refute the Pythagorean doctrine of vision; and he mentions that the visual rays by which objects are seen, form a cone whose apex is in the eye, and whose base is on the object. He proves, in a very short and perspicuous manner, that the angles of incidence and reflexion are equal, and that both the rays are in a place at right angles to the reflecting surface. He shows that, in concave mirrors, the objects appear concave, and in convex ones, convex; that the apparent place of an image formed by a polished mirror is at the place where the reflected ray cuts the line drawn from the object to the centre of the sphere; that objects appear smaller in concave and convex mirrors, and that in convex mirrors, objects appear on the side in which they are actually situated. From the general incorrectness by which this treatise is characterized, as well as the number of errors with which it abounds, some authors have been of opinion, that it was not the production of the great geometer, while other suppose that it has received additions and alterations from the hands of succeeding authors. There can be no doubt, however, from the testimony of Proclus and Theon, that Euclid wrote a work on optics; and though the imperfect nature of the data, and the inaccuracy of his reasoning, are very unlike what might have been expected from such a skilful geometer, yet, as Montucla has well remarked, there are at all times numerous examples of natural philosophers, whose sagacity and acuteness appear only in their geometrical writings.

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[*] These writings were traced on wax, spread over a more solid substance. Pliny also mentions globes of glass, which, when held to the sun, produced combustion; and Lactantius, A. D. 303, informs us that a glass globe, full of water, and held to the sun, could light a fire even in the coldest weather.

[†] This treatise is published in the Oxford edition of his works. A Latin translation of it by John Pena was published at Paris in 1557.

From the time of Euclid to that of Seneca, no progress seems to have been made in the study of optics. Seneca observed, that small letters, seen through a bottle of glass filled with water, appear larger; and the reason which he assigned for this effect was, "that the eye slides in the water, and cannot lay hold of its object, (*quod acies nostra in humido labitur, nec apprehendere quod vult fideliter potest.*) The colour produced by an angular piece of glass, seems to have excited the attention of Seneca. He remarked, that such a piece of glass produced all the colours of the rainbow; but he regarded the colour as not *real*, but as false, like that which appears on the neck of a pigeon, and which changes with the position of the observer. The same false colour, he remarks, is that of a speculum, which has no colour of its own, but assumes that of any other body. Seneca likewise mentions the magnifying power of concave mirrors; but in his speculations respecting the rainbow, he has rather obscured than improved the conceptions of Aristotle. He considers the circular shape of rainbows and halos, as occasioned by the motion communicated to the atmosphere, and the vapours it contains, by the impulse of light, the effect of which he supposes must be circular, like the waves produced by a stone falling on the surface of water. He considers the rainbow as the image of the sun reflected from a hollow and moist cloud; and he supposes that the colours come partly from the sun, and partly from the cloud.

Cleomedes, who flourished about 50 years after Christ, has given, at the end of his *Cyclical Theory of Meteors*, a name then applied to the stars, a very detailed account of the manner in which vision was supposed to be performed by those who rejected the rational theory of Pythagoras. They supposed that the visual ray set out from the eye, and moved in a straight line till it encountered some obstacle. If the obstacle was impenetrable, it reflected the visual ray, forming equal angles on each side of the perpendicular. In this new direction it seized the object which was found in its way, and in this manner it rendered it visible. If the body was penetrable, the visual ray passed through it, and assumed the tint of the penetrable medium, which they called diaphanous. If the visual ray passed from a diaphanous medium more rare, such as air, into a diaphanous medium more dense, such as water or glass, it inclined towards the perpendicular, and seized the object which it met in this new direction. If, on the contrary, the second diaphanous body was rarer than the first, the visual ray inclined towards the other side, or towards the prolongation of the perpendicular, that is, instead of approaching the first perpendicular, it receded from it.[*]

The most celebrated of all the ancient writers on Optics was Claudius Ptolemy,[†] the illustrious astronomer of Alexandria, who flourished about the middle of the second century. His work, which existed in the time of Roger Bacon, has been long supposed to be lost, and it was known, only from those authors who had seen it, that it treated fully on astronomical refractions, and contained a rational explanation of the enlargement of the horizontal moon. Montucla informs us, that in the catalogue of the Bodleian library at Oxford, p. 300, there is a work, entitled, *Ptolemei Opticorum Sermones quinque ex Arabico Latine versi;* but though he mentions the circumstance as a proof that the work of Ptolemy is not lost, no person, so far as we know, has thought of looking into this valuable and interesting MS.[‡] In his Exposition of the System of the World, M. Laplace expressly states, that there is a similar MS. in the Royal Library at Paris, and in consequence of this, M. Humboldt was induced to examine the MS. and to communicate it to the celebrated French astronomer, M. le Chevalier Delambre, who has published a full analysis of it in the *Connaissance des Tems* for 1816.

The optics of Ptolemy consists of Five books. The *First* book is wanting, but from the recapitulation of it at the beginning of the second, it appears to have contained a dissertation on the relations between light and vision, founded on the idea that the visual rays issue from the eye. In the *Second* book, he shows that we see better with two eyes than with one, and that the object is not seen in the same place with one eye as with two. Vision, he says, is single, if the two axes of the pyramids of the visual rays are directed in the same manner on the object, but becomes double, if the axes are not directed in a similar manner, and if the distance is a little less than the distance between the eyes. He next proceeds to find geometrically the circumstances which produce single or double images. He ascribes imperfection of sight in old men to a want of the visual virtue, which, like the other faculties, decays with the approach of age; and he states, that these who have *concave* eyes see at a less distance than those who have not such eyes. Rapidity of motion, he asserts, confounds the colours on a wheel. If the colour is in the direction of a ray, the wheel will appear entirely of this colour, and if different colours are at different distances from the centre, these will appear on the wheel as so many concentric circles differently coloured. When, after looking long at a coloured object, we direct the eye to another, we attribute to it the colour of the first. In the *Third* book, which treats of mirrors, he shows, that in a plain mirror, the object is seen in the perpendicular drawn from the object to the plane of the mirror, and continued behind it. He mentions, that objects appear smaller towards the zenith, and larger towards the horizon, because, in the former case we see them in a position to which we are less accustomed. In concave mirrors the objects appear concave, and in convex ones they appear convex, and the image is seen at the point of intersection of the reflected ray, and the line drawn from the object to the centre of the sphere. The *Fourth* book treats of concave mirrors. In these mirrors an object may be reflected and rendered visible by all the parts of the mirror, or by three, or two, or even one point. The image may be either on the surface of the mirror, or before the surface, or behind the eye, or behind the mirror. When the image is beind the mirror, the distance of the object from the mirror is less than that of the image. When the image is between the eye and the mirror, the distance of the object from the eye will be sometimes greater than the distance of the image from the mirror, and sometimes it will be equal to it, and sometimes less. When the object is between the mirror and the eye, it will be seen in a part different from that where it really is; and if we give it a motion in one direction, it will appear to move in the opposite direction. The *Fifth* book is the most curious and valuable of the whole work. Ptolemy begins by explaining the experiment with the piece of money, which, when concealed behind the sides of a vessel, becomes visible by filling it with water. The refraction of the visual ray in penetrating the water, makes us see the piece of money out of its true place, and in the prolongation of the primitive direction of the ray emitted from the eye. In order to measure this refraction at different angles, Ptolemy employs a circle divided into 360°, the inferior half of which is plunged in the water, so that the refracting surface covers one of the diameters of the circle. The centre of the circle is marked by a small coloured body, and a second similar body is fitted to one of the quadrants out of the water, and at a given distance from the vertical diameter; a third coloured body slides on the lower part, which is immersed in the water. This last body is then pushed with a rod till the eye placed on the body in the air sees all the three in a straight line. The two distances of the second and third body from the vertical diameter are then measured on the graduated circle.

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[*] Delambre, *De L'Optique de Ptolemée*, in the *Connaissance des Tems*, 1816, p. 243.

[†] See our article ASTRONOMY.

[‡] This interesting MS. which Professor Rigaud has had the kindness to examine at our request, belongs to the *Savilian*, and not to the *Bodleian* library; and was the property of Sir Henry Savile himself. It consists of 270 pages of small quarto. The first book is wanting, as in the Paris MS. There are no blank spaces in this as there is in the Paris MS.; and it has also a preface of the translator, giving a general abstract of the work, and stating that the fifth book is imperfect. This preface does not appear from Delambre's analysis to exist in the Paris MS.

In this manner Ptolemy obtained the results in the following table, which contains the angles of refraction from *Air to Water*, from 10° up to 80° of incidence.

Angles of Incidence.	Angles of Refraction.		Ratio of the Sines.
0°	0°	0′	. . .
10	8	0	0.80143
20	15	30	0.78136
30	22	30	0.76537
40	28	0	0.73037
50	35		0.74875
60	40	30	0.76992
70	45	0*	0.75249
80	50	0	0.77786
Mean ratio of the sines.†			0.76736

In order to measure the angles of refraction from air into glass, Ptolemy adopted the ingenious idea of procuring a semi-cylinder of pure glass, and adjusting the diameter of it so as to coincide with the horizontal diameter of the graduated circle already described. By performing the very same experiments which he made with water, he found that there was no refraction at a perpendicular incidence; but that for every other position, the angle in the air was always greater than the angle in the glass, and the refraction greater than in water. When the three bodies were placed in appearance in the same straight line, they always remained there, whether the eye was placed above the glass or below it. The following are the refractions from *Air* to *Glass*, which he obtained in this manner:

Angles of Incidence.	Angles of Refraction.		Ratio of the sines.
0°	0°	0′	. . .
10	7	0	0.70179
20	13	30	0.68255
30	20	30‡	0.70041
40	25	0	0.65748
50	30	0	0.65270
60	34	30	0.65403
70	38	30	0.66247
80	42	0	0.67946
Mean ratio of the sines§			0.67386

When the semi-cylinder of glass was placed on the surface of water, Ptolemy observed that the refractions from water into glass were less than any he had observed, because the difference of density between *Water* and *Glass* was less than between water and air. The following were the results which he obtained:

Angles of Incidence.	Angles of Refraction.		Ratio of the Sines.
0°	0°	0′	. . .
10	9	30	0.95044
20	18	30	0.92774
30	27	0	0.90798
40	35	0	0.89233
50	42	30	0.88192
60	49	30	0.87804
70	56	0	0.88422
80	62	0	0.89657
Mean ratio of the sines			0.90190

Ptolemy now proceeds to the important subject of astronomical refraction, which he ascribes to the difference of density between ether and air. If the visual ray, he remarks, is stopped by an impenetrable body, it could not show us a body which is hid behind the first; and if the second becomes visible, it can only be on account of the flexion of the visible ray. This flexion takes place at its passage into a medium of different density; and the possibility of this flexion, he asserts, may be proved by the following phenomena. By observations on the stars, it was found that the parallels drawn through the apparent place of those which rise or set, are then nearer the north pole than the parallels which pass through their apparent place when they are on the meridian; and the nearer the stars are to the horizon, the greater is the approach of their parallels to the pole. By observing a circumpolar star, Ptolemy found that it was nearer the pole in its lower passage across the meridian; but when it was near the zenith its parallel became greater in appearance, whereas in the first case it became smaller. Hence it follows that refraction raises the stars towards the zenith. In order to explain the manner in which refraction operates, Ptolemy makes use of the same figure upon which Cassini has since founded all his theory, and he employs almost the same reasoning in order to determine the quantity of the refraction. He remarks, that the more a star is elevated, the less will be the difference between its true and its apparent place, and that this difference will be nothing in the zenith, because a perpendicular ray experiences no flexion. He demonstrates by a figure, that in every case the refraction carries the star towards the zenith; and he states that the height of the atmosphere is unknown, but that it must begin below the sphere of the moon. From this general account of the fifth book of the optics of Ptolemy, it will be seen that he gives a theory of astronomical refractions much more complete than that of any astronomer before the time of Cassini.

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* This is 45° 30′ in the Oxford MS.

† This mean ratio differs little from that given by Newton, which is 0.74858.

‡ This is 18° 30′ in the Oxford MS. Professor Rigaud conjectures that the real number in the MS. has been 19° 30′.

§ This mean ratio differs little from that given by Newton, which is 0.64516.

After a long interval of inactivity, the science of optics was cultivated with assiduity in Arabia. Al Farabius wrote a treatise on Perspective about A. D. 900; and Ebn Haithem is said to have produced a work which treated of direct, reflected, and refracted vision, and also of burning mirrors; but this production has been unfortunately lost.

The only optical work, indeed, of the Arabian philosophers, which has reached our times, is the Treatise on Optics,* by Alhazen, who flourished about the end of the eleventh century. Montucla has stated, without sufficient evidence, that Alhazen seems to have borrowed from Ptolemy the greater part of his optics; but M. Delambre, in the paper already quoted, has successfully repelled this imputation against the honour of the Arabian philosopher. Instead of finding any reason for believing that he has borrowed almost all his optics from Ptolemy, M. Delambre supposes it quite probable that he may never even have read that work. In treating of refraction, Alhazen has not copied the tables of Ptolemy, which we have inserted above, and in what he says of astronomical refraction, he has given a much less complete view of the subject. The plan of Alhazen's work, too, as M. Delambre remarks, is quite different; he speaks a language less metaphysical and more geometrical, and he discusses a number of questions, and resolves a quantity of problems, to which Potolemy does not even allude. The physics of Ptolemy are much more defective than those of Alhazen; and in the part which is purely geometrical, the work of Alhazen is also superior to that of Ptolemy.

The Arabian philosopher must be considered as having made a great step in the science, when he refuted the opinions concerning vision, which had been so long established. He proves that the rays which produce vision, come from the object to the eye. He gives an anatomical description of the eye, explains the share which each of its parts has in vision, and accounts for single vision with two eyes, by supposing that, when two corresponding parts of the retina are affected, the mind perceives but one image. Alhazen describes *seven* species of mirrors, whereas Ptolemy had considered only three; and he has the sole merit of determining in general the focus of reflected rays, when the place of the eye and that of the object are known,—an honour which Montucla, without evidence, supposes to belong to Ptolemy. Alhazen's instrument for measuring refraction is much more complex than that of Ptolemy; and all that he says, both on the refraction of fluids and on that of the atmosphere,† is much less perfect. Alhazen observed that refraction contracts the diameters and distances of the heavenly bodies; and he supposes it to be the cause of the twinkling of the stars. He treats fully of *optical deceptions* as produced by direct vision, as well as in vision by refracted and reflected light.

In the year 1270, Vitello, a native of Poland, drew up a very voluminous work on optics, which, though less prolix and more methodical than that of Alhazen, has in general been considered as little more than a translation of it. This, however, is too harsh a censure upon the Polish philosopher, though at the same time it may be considered as a just punishment for his having denied that he had any knowledge of the work of Alhazen.‡ His experiments on the refraction of light by water and glass, are much more correct than those of Ptolemy; and it is strange that the comparison of his own results did not lead him to the discovery of the constant ratio of the sines of the angles of incidence and refraction. The following Tables contain the results of all his experiments.

Table of Refractions from the Optics of Vitello.

From Air into Water.				From Water into Air.				From Air into Glass.		
Angle of Incidence.	Angle of Refraction.		Ratio of the Sines.	Angle of Refraction, Vitello.		Real Angle.		Angle of Refraction.		Ratio of the Sines.
0°	0°	0′	. .	0°	0′	0°	0′	0°	0′	. .
10	7	45	0.77658	12	15	16	37	7	0	0.70178
20	15	30	0.78135	24	30	25	35	13	30	0.68255
30	22	30	0.76537	37	30	40	52	19	30	0.66761
40	29	0	0.75423	51	0	57	16	25	0	0 65748
50	35	0	0.74875	65	0	.	.	30	0	0.65270
60	40	50	0.74992	79	30	.	.	34	30	0.65403
70	45	30	0.75904	94	30	.	.	38	30	0.66247
80	50	6	0.77787	120	0	.	.	42	0	0.67946
Mean ratio 0.76414								Mean ratio 0.66976		

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* This work, translated from the Arabic, was published for the first time in 1572 by Risner along with the work of Vitello, under the title of *Thesaurus Opticæ*, Bas. 1572. It appeared also along with the work of Nonius on Twilight.

† M. Delambre considers it as deducible from Alhazen's reasoning, that he considered the stars as elevated towards the *pole* by refraction, in place of towards the *zenith*.

‡ Vitello afterwards retracted this denial, and acknowledged himself a disciple of the Arabian philosopher.

From Glass into Air.					From Water into Air.			From Glass into Water.			
Angle of Incidence.	Angle of Refraction.		Real Angle.		Angle of Refraction.		Ratio of the Sines.	Angle of Refraction.		Real Angle.	
0°	0°	0′	0°	0′	0°	0′	. .	0°	0′	0°	0′
10	13	0	15	2	9	30	0.95043	10	30	11	6
20	26	30	30	42	18	30	0.92773	21	30	22	17
30	40	30	78	17	27	0	0 90798	33	0	33	40
40	55	0	73	41	35	0	0.89233	45	0	45	27
50	70	0	.	.	42	50	0 88192	57	30	58	9
60	85	50	.	.	49	30	0.87804	70	30	73	47
70	101	30	.	.	56	0	0 88224	84	0	.	.
80	118	0	.	.	62	0	0.89657	98	0	.	.
					Mean ratio 0.90190						

From these Tables it appears that the average mean ratio of the sines, both in the refraction of water and glass, is more correct than that of Ptolemy. Thus

	Water.	Glass.
Ptolemy	0 76736	0.68736
Vitello	0.76414	0.66976
Newton	0.74858	0.64516

and the correctness of the individual results, when compared with those of Ptolemy, will be manifest, by comparing the ratio of the sines for each angle with the mean ratio of the whole. In his experiments on the refraction of light, in passing from a dense into a rare medium, he found that the angles were exactly the same as when the light passed from a rare into a dense medium; and upon this principle he seems to have computed the refractions in the last row of Tables.

Vitello observed, that wherever light suffered refraction or reflexion, a certain part of it was lost, and the bodies always appeared less luminous; but he does not attempt to estimate the quantity of it. He ascribes the twinkling of the stars to the motion of the air in which the light is refracted; and in an experimental illustration of this opinion, he observes that the twinkling is increased when the stars are viewed through water put in motion. In treating of the rainbow, he proves that refraction, as well as reflexion, is necessary to its production; but he seems to consider the refraction not as producing the colours, but merely as serving to condense the light, and enable it to make a stronger impression on the eye. The three colours which he supposes to exist in the rainbow, he ascribes to a mixture of the sun's light with the blackness of the cloud from which they are reflected. He endeavours to show, that in some countries a rainbow cannot be seen at mid-day, viz. when the sun is higher than the semidiameter of the bow, the centres of the sun and the bow being always in a right line, passing through the eye of the observer. In order to exhibit colours similar to those of the rainbow, he laid a piece of white paper under a circular glass vessel filled with water, and, when it was exposed to the sun, he saw colours which he considered as analogous to those of the rainbow. The foci of spheres of glass, and the apparent size of objects seen through them, are also among the topics discussed by the Polish optician. Considering that the focus of rays falling perpendicularly upon every point of the sphere must be in its centre, he supposes that this must also be the focus of the solar rays; and as it was impracticable to determine the truth of this supposition experimentally, he suggested that a hemisphere, or a still less portion of a sphere, might be employed to make the experiment. This mistake of Vitello, in confounding the focus of rays converging to the centre of the sphere with the focus of parallel rays, has been censured by Baptista Porta; but the learned Italian should at the same time have stated, that Vitello demonstrates the possibility of firing bodies placed beyond the sphere by the transmitted rays of the sun.*

About ten years after the appearance of Vitello's optics, Thomas Peckham, Archbishop of Canterbury, published a treatise on optics entitled *Perspectiva Communis*, or a treatise on direct optics, accompanied with an abridgment of catoptrics. This work, which was long considered as classical, went through many editions, though it contained nothing that was either very new or very important.

Our celebrated countryman Roger Bacon, appears to have devoted a great share of his attention to the subject of optics. But though he studied the works of Alhazen, and of the other Arabian authors, he does not seem to have added any thing very important to the science. In his *Perspectiva* and his *Specula Mathematica*, he has treated largely of optical subjects; but these are only detached portions of his *Opus Majus*, which contains an account of all his inventions and views. In this work he describes, in the clearest manner, the magnifying effects produced by the use of convex lenses; and if he was unacquainted with spectacles and telescopes, he has certainly anticipated their invention in language more than prophetic. Wood, in his History of Oxford, Jebb, the editor of *Opus Majus*, and Molyneux, in his Dioptrics, have all concurred in regarding Bacon as the inventor of the telescope; and though we consider the question as not unattended with difficulties, we cannot but be convinced that many an invention has been awarded on much less obscure grounds than those upon which the telescope and microscope are given to Roger Bacon.

The following is a translation of the whole passage respecting convex lenses, which obviously describes the single microscope and spectacles.

"If the letters of a book, or any minute object, be viewed through a lesser segment of a sphere of glass or crystal, whose plane base is laid upon them, they will appear far better and larger. Because, by the fifth canon about a spherical medium whose convexity is towards the eye, and the object is placed below it, and

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* Vitello's work on optics was published alone in 1535 and 1551 at Nuremburg, and afterwards along with that of Alhazen, in Risner's *Thesaurus Opticæ*, already mentioned.

between the convexity and its centre, all things concur to magnify it. For the angle under which it is seen is greater, and its image is also greater and nearer to the eye than the object itself, because the object is between the centre and the eye; and therefore this instrument is useful to old men, and to those that have weak eyes; for they may see the smallest letters sufficiently magnified. But if the medium be the larger segment of a sphere, or but half of one, then, by the sixth canon, the apparent visual angle will be greater than the true, and the image also greater than the object; but the place of it will be beyond the object, because the centre of the sphere is between the eye and the object; and, therefore, this instrument is not so powerful in magnifying as a lesser segment of a sphere. Also instruments made of crystal bodies with plane surfaces, by the first canon about planes, and with concave surfaces, by the first and second canons about spherical surfaces, will perform the same thing. But the lesser of two segments of a sphere magnifies more manifestly than any of them all, by reason of the concurrence of all the three causes, as I said before."

The passage which relates to the telescope and microscope is as follows:

"Greater things than these may be performed by refracted vision. For it is easy to understand by the canons above mentioned, that the greatest things may appear exceeding small, and on the contrary; also that the most remote objects may appear just at hand, and on the contrary. For we can give such figures to transparent bodies, and dispose them in such order with respect to the eye and the objects, that the rays shall be refracted and bent towards any place we please; so that we shall see the object near at hand, or at a distance, under any angle we please. And thus from an incredible distance we may read the smallest letters, and may number the smallest particles of dust and sand, by reason of the greatness of the angle under which we may see them; and on the contrary, we may not be able to see the greatest bodies just by us, by reason of the smallness of the angles under which they may appear; for distance does not affect this kind of vision, excepting by accident, but the quantity of the angle. And thus a boy may appear to be a giant, and a man as big as a mountain, for as much as we may see the man under as great an angle as the mountain, and as near as we please; and thus a small army may appear a very great one, and, though very far off, yet very near us, and on the contrary. Thus also the sun, moon, and stars, may be made to descend hither in appearance, and to appear over the heads of our enemies; and many things of the like sort, which would astonish unskilful persons."

It is scarcely possible to read this passage, and entertain the sober conviction that Bacon had never put his speculations to the test of experiment. He speaks, indeed, with all the conviction of actual trial, and should it be found that what he says is mere speculation, we must still entertain the opinion, that he was the first person who actually believed, and published his belief, *that small objects could be magnified, and distant objects brought near, by means of single lenses, and combinations of lenses*, and that these effects were produced by enlarging by means of refraction the visual angles under which these objects were seen. Dr. Smith has endeavoured to repel the arguments in favour of Bacon being the inventor of the telescope, by pointing out the errors and inconsistencies of his speculations; but there are many instances in the history of science, where inventions have been made by persons who knew little or nothing of the very principles upon which they were founded. That Bacon magnified objects with his lesser sphere, or a convex lens, is indubitable; and when we consider that a single lens, or a single concave mirror, held at a distance from the eye, constitutes in reality a telescope, the eye performing the functions of an eye-glass, we can scarcely doubt that Bacon invented at least a telescope of this description.

If the invention of spectacles and of telescopes was not made by Roger Bacon, he at least prepared the way for their immediate introduction. It seems quite certain, that spectacles were well known about the time of Bacon's death. Alexander Spina, of Pisa, who died in 1313, and who happened to see a pair of spectacles in the possession of another person, immediately constructed a pair for himself; and Muschenbroek informs us, that it is inscribed on the tomb of Salvinus Armatus, a nobleman of Florence, who died in 1317, that he was the inventor of spectacles.

These views receive no inconsiderable support from statements contained in Recorde's *Pathway to Knowledge*, and in the *Pantometria* and *Stratioticos* of Leonard Digges. In the first of these works, which was printed in 1551, the author, who is said to have been physician to Edward VI. to whom he dedicates his book, observes, "Great talke there is of a glasse he (viz. Frier Bakon, as he calls him) made at Oxford, in which men might see things that weare don, and that was iudged to be don by power of euill spirites. But I know the reason of it to be good and naturall, and to be wrought by geometry, (with perspective as a part of it,) and to stand as well with reason as to see your face in a common glass."

The *Pantometria* of Leonard Digges was first printed in London in 1571, and a second edition of it by his son, Thomas Digges, Esq. appeared in 1591. In the preface to this second edition he makes the following curious remarks: "My father, by his continuell painfull practices, assisted by demonstrations mathematical, was able, and sundrie times hath by proportional glasses duely situate in convenient angles, not only discovered things farre off, read letters, numbered pieces of money, with the verye coyne and superscription thereof, cast by some of his freends of purpose upon downes in the open fields; but also seven myles off declared what hath been done in private places." In the 21st chapter of the first book, Leonard Digges himself says, "But marvellous are the conclusions that may be performed by glasses (mirrors) concave and convex, of circular and parabolic forms, using for multiplication of beams sometimes the aid of glasses transposed, which by practice should unite or dissipate the images or figures presented by the reflection of others. By these kind of glasses, or rather frames of them placed in due angles, yee may not only set out the proportion of an whole region, yea, represent before your eye the lively image of every house, village, &c. and that in as little or great space or plan as ye will presente; but also augment or dilate any parcell thereof, so that whereas at the first appearance a whole town shall present itself so small and compact together, that ye shall not discover any difference of streets, yee may, by application of glasses in due proportion, cause any peculiar house or room thereof dilate and show itself in as ample form as the whole town at first appeared, so that yee shall discern any trifle, or read any letter lying there open, especially if the sun's beams may come into it, as plainly as if you were corporally present, although it be distant from you as far as eye can descrie. But of these conclusions I mind not here more to intreate, having at large in a volume by itself opened the miraculous effects of perspective glasses."

It is impossible, we think, to read the preceding extracts, and compare them with the passages from Recorde and Roger Bacon, without being convinced that the camera obscura, and telescopic combinations of mirrors and lenses, had been used in England before the time of Baptista Porta and Jansen. It is probable that the mirrors and lenses were placed on stands or in frames, that the objects were seen and magnified by oblique vision, and that on this account it was necessary to place them at convenient angles, as mentioned both by Digges and Roger Bacon. The great respectability and good character, both of Leonard and Thomas Digges, who were grandfather and father to Sir Dudley Digges, and were descended from an ancient and respectable family, prevent us from supposing that they could have described inventions which they had not themselves seen.

No farther progress was made in the science of optics till near the beginning of the sixteenth century, when Maurolycus of Messina published his *Theoremata de Lumine et Umbra*, and his *Diaphanorum Partes, seu Libri Tres*. The first of these works which was completed in 1525, treats of the measure of light, or the illumination of bodies; but it is chiefly remarkable for the solution which Maurolycus has given of the problem which had perplexed all optical writers from the time of Aristotle. It had often been observed, that when the sun shone through an aperture of any form, the figure of the aperture appeared always round; and in like manner, when the sun had the form of a crescent during an eclipse, the form of every aperture through which his rays passed was that of a crescent. In explaining these phenomena, Maurolycus remarks, that each part of the aperture is the summit of two opposite cones of rays, one of which has the sun for its base, and the other being cut by a plane perpendicular to its axis, will produce a luminous circle, whose diameter will be proportional to the distance of the plane of intersection from the aperture. There will, therefore, be painted on the opposite plane as many equal circles of light as there are points in the aperture. Hence if we describe on this plane a figure equal and similarly placed to that of the aperture, and if on each of these points we describe a multitude of circles, the figure which they will form will be precisely that of the image of the sun. For the very same reason the image will be a cresent when the sun is a crescent.

In explaining the phenomena of vision, Maurolycus considers the crystalline lens as the principal organ, and as transmitting to the optic nerve the images of objects. The Italian philosopher had the merit of discovering the reason why some persons are long-sighted and others short-sighted. He shows that in the former case the rays have not been converged to a focus when they reach the retina; while in the latter case they have been converged before they reach it. Hence he finds that the convergency may be hastened in long-sighted persons, or distinct vision produced, by the use of a convex lens; and that the convergency may be delayed in short-sighted persons, or distinct vision produced, by the use of concave glasses. The formation of images at the bottom of the eye seems to have eluded the sagacity of Maurolycus from the difficulty of reconciling an inverted image with an erect object,—a difficulty which at a later period perplexed the ingenuity of Kepler himself. Maurolycus attempted, like his predecessors, to explain the formation of the rainbow; but his labours were not crowned with success. He found the semidiameter of the interior bow 42°, and of the exterior one from 53° to 54°; but, according to his theory, these numbers should have been 45° and 56°; for he considered the solar ray as partly reflected from the exterior of the drop, and partly entering into the drop, and circulating there by several reflections along the sides of an octagon. He supposed that there were four colours in the rainbow, viz. orange, (*crocus*,) green, blue, and purple. Maurolycus imagined that he had discovered the true law of refraction. He supposed that the angle of refraction was proportional to the angle of incidence, and was always three-eighths of that angle when when the refraction was made from air into glass. Maurolycus was the first person who observed what have since been called caustic curves, as formed by refraction. He remarked that when light passed through a transparent sphere, a curve was formed by the continued intersections of the refracted rays, and that the rays did not converge to one point; and he observed that the rays incident at the greatest distance from the axis, again met the axis after their refraction, at points nearer the sphere than those rays which were incident near the axis. By this means a sort of cone of light was generated, having its concave sides formed by the intersection of the different refracted rays.

Contemporary with Maurolycus was the celebrated Neapolitan philosopher, Joannes Baptista Porta, who has rendered himself more famous by his ardour as a collector of mysteries, than others have done by the discovery of new facts. Having instituted what he called an *Academy of Secrets*, which met at his own house in Naples, and embraced all the ingenious individuals which that city contained, he spared neither labour nor expense in collecting all the remarkable facts and experiments in physical science. By his own exertions, and those of the members of his academy, he was enabled to compose his *Magia Naturalis*, a work which, as Montucla has observed, is filled with pretended observations, compiled in general with more credulity than judgment. His work appeared in the year 1560, when he was only about fifteen years of age, and a second edition appeared about thirty years afterwards, with numerous alterations and additions. At its first appearance it was translated into French, Italian, Spanish, and Arabic, and underwent various editions in different countries; and though it is a wonderful collection of every thing remarkable that was known at the time, yet it is principally celebrated in the history of optics for the description which it contains of the camera obscura. Baptista Porto observes, in the seventeenth chapter, that if a small hole be made in the shutter of a window, the images of all external objects will be represented on the wall in their proper colours; and that if a convex glass be fixed in the aperture, so that the images are viewed at the distance of its focal length, they will be rendered much more distinct, so that even the features of a person out of the room may be distinguished in his image on the wall. In order to make the images formed on the camera obscura erect, he recommends that they should be viewed upon a convex mirror, properly adapted to the convex glass, and kept at a proper distance from the aperture. Not satisfied with the mere exhibition of images of external objects on the wall, Baptista Porta applied his invention to the representation of eclipses of the sun, and of pictures of drawings which were placed on the outside of the convex lens, and at such a distance that their images were distinctly formed on the wall. By giving motion to these pictures and drawings, he exhibited the appearance of a hunt, of battles, and of other scenes, which in these times excited no small degree of astonishment. In studying the images formed in his camera obscura, Baptista Porta could not fail to observe that they were magnified, and, therefore, seen more distinctly than with the naked eye; and he accordingly found, by placing his eye behind a convex lens, that he could read a letter which he could not read with his naked eye. In this case his eye was placed six or seven inches behind the image formed by the convex lens, and consequently this instrument was a telescope, in which his eye performed the part of an eye-glass, as in the instrument which Roger Bacon seems to have employed.

The phenomena of the camera conducted its inventor to some just views regarding vision. He maintained that vision is performed by the entrance of rays into the eye; that the pupil, which he observed to contract and dilate when exposed to different lights, was analogous to the hole in his window-shutter, and that the crystalline lens was the principal organ of vision. It appears, however, that he did not regard the crystalline lens as performing the part of his convex lens, but rather considered it as corresponding to the ground which received the image. This strange mistake is not easily accounted for. The discovery of the contraction and dilatation of the pupil seems to have been made so early as 1522, by Achillinus, and also at a later period by Father Paul of Venice.

In the year 1593, Baptista Porta published another work, which he entitled *De Refractione Optices parte libri novem*, and in which he discusses a great variety of optical subjects, sometimes with acuteness and discernment, and at other times in a manner very vague and incorrect. The zeal and ardour of Baptista Porta, are always more prominent than his genius; and it is rather singular, that a philosopher who knew so much of what was done by others, and who made so many experiments, should have almost no other claim upon the gratitude of posterity, than the invention of the camera, which, after all, was probably communicated to him.

The subject of the rainbow began about this time to occupy the particular attention of philosophers. J. Clichtoveus, who died in 1543, considered the exterior bow as a reflected image of the interior one, and in this manner endeavoured to account for the faintness of its light, as well as the inverted order of its colours. A more important view of the subject was afterwards given by J. Fleschier of Breslau, in a work entitled *De Iridibus doctrina Aristotelis et Vitellionis*, which appeared in 1571. This author ingeniously ascribes the phenomena of the rainbow to two refractions, and an intermediate reflexion within the drop; but after the ray had thus acquired its colours, he supposed that it was again reflected from another drop before it reached the eye of the spectator. A still nearer approach to the true cause of the phenomenon, was made by the celebrated Kepler, in a letter to our eminent countryman Harriot, written in 1606. He conceives that a solar ray, which is a tangent to the drop of rain, is first refracted into the drop, and after suffering a reflexion from the bottom of the drop, is again refracted to the eye of the spectator. This is no doubt very nearly the progress of the rays; but Kepler was wrong in supposing that the rays which were tangents to the drop reached the eye of the observer; for if this were the case, the diameter of the bow, as Montucla has remarked, would be only 14° 24′.

A happy experiment seems to have at last suggested the true theory of the rainbow to a writer of very slender attainments. Mark Antony de Dominis, archbishop of Spalatro, in a treatise *De Radiis Visus et Lucis*, published in 1611, by Bartolus, maintains that one reflexion and two refractions in the drop of water, were sufficient to bring the rays that formed the bow to the eye of the spectator. This explanation was either verified or suggested by a globe of glass, filled with water, which he viewed when exposed to the solar ray, under the same circumstances as the drops of rain. In this way he found that the colours were the same, and arranged in the same order as in the natural bow. De Dominis supposed that the red rays were those which emerged nearest to the bottom of the drop, and that, having traversed the least quantity of water, they thus preserved a greater intensity than the green and blue rays, which, emerging at a part of the drop most remote from the bottom, passed through a greater quantity of water, and were therefore less brilliant. He likewise remarked, that all the rays of the same colour must emerge from the drop of water at a part similarly situated with regard to the bottom of the drop centrally opposite to the sun, and that they therefore ought to form equal angles with a line drawn from the sun, through the eye of the spectator. Hence it follows that the zones of colour should appear circular; and as the red rays form a greater angle with the above line, they ought to appear more elevated, and the red zone ought to be the exterior one. The vagueness and general inaccuracy of the reasoning of De Dominis has led some French authors to deprive him of all that merit which both Montucla and Priestley have concurred in assigning to him. His explanation of the interior bow, it is true, is sufficiently absurd; and his observations on vision and colours are of the most crude kind; but whatever be his errors, and however vague and indefinite be his explanations, it is impossible for any philosopher, free from the influence of national partiality, to deny that the Italian prelate has given such an explanation of the general phenomena of the exterior bow, that any other philosopher of more optical knowledge and of inferior acuteness could not fail, without any stretch of intellect, to give precision and perfection to the explanation. This unfortunate author, who had risen to such high ecclesiastical honours, had the imprudence to express sentiments inconsistent with his situation, and was obliged to leave Italy, and take refuge, in the year 1616, in London, where he spent some years. Being induced by various promises to return to Italy, his indiscretion again involved him in new troubles, and having been arrested by Pope Urban VIII. he was imprisoned in the Inquisition, where he died of poison.*

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* The reader who wishes to study the controversy respecting De Dominis, may consult Montucla, vol. i. p. 703; Priestley *on Vision*, vol. i. p. 51; Klugel's *Translation of Priestley*; Newton's *Optics*, p. 154; Noceti's Poem *de Iride*, with Boscovich's Notes; Bossut's *Hist. Gen. des Mathematiques*, vol. i. p. 371, and Biot's *Traité de Physique*, iii. p. 368.

If the telescope was not actually invented by Roger Bacon, or by Baptista Porta, the science of optics had now attained that degree of maturity, when its invention, as well as that of the microscope, was almost inevitable. If any of these valuable instruments had been the unequivocal invention of a single individual, at a time when they were utterly unknown, the remarkable effects which they produced must have excited universal attention, and secured to the inventor a reputation of the highest order. It is a remarkable fact, however, that no well founded claim to the invention of the telescope has yet been made out; and the number of competitors for this honour affords the most unequivocal evidence that the telescope was brought into the condition of a portable and efficient instrument by steps so gradual, that no individual had any real claim to be regarded as its inventor.

Roger Bacon declared in the most distinct language, that distant objects might be brought nearer, and seen more distinctly, by means of a lens or lenses; and Baptista Porta actually read a letter, which was illegible with his naked eye, by viewing the image of it formed in the focus of a convex glass. Nothing was therefore wanting but to increase the effect by means of an eyeglass, and this might have been readily done by accident, by any long or short-sighted person who repeated the experiment of Baptista Porta, with a concave or a convex pair of spectacles. We have no doubt, therefore, that the telescope *was known as an experiment long before it was known as an instrument*, and that many ingenious persons, without any communication with one another, had constructed the instrument in a portable and efficient form.

The celebrated Descartes has stated, at the beginning of his Dioptrics, published in 1637, that the telescope was invented about thirty years before, by James Metius, a Dutchman, and citizen of Alkmaer, who accidentally thought of looking through two lenses at a time, when he was amusing himself with mirrors and burning glasses. One of these glasses happened to be convex and the other concave, and having been casually well adjusted at the opposite ends of a tube, he was surprised to observe that distant objects seen through it were large and distinct.

Passing by, as unworthy of notice and unsupported by evidence, the story of the telescope being invented by the children of John Lipperheim, a spectacle-maker of Middleburg, in Zealand, we shall proceed to consider the claims of Zacharias Jansen, as urged by Borelli in his treatise *De Vero Telescopii Inventore*. In this work, which appeared at the Hague in 1655, Borelli has published the affidavits of several inhabitants of the city of Middleburg, taken before the consuls in the year 1655. The son of Zacharias Jansen declares that his father made telescopes in the year 1590, (as he had often been informed,) and his sister refers the invention to 1610. Another person affirms on his own knowledge, that his neighbour, Hans Lipperhey (*Lapprey* or *Lipperheim*) made telescopes before the year 1605, while other two witnesses aver that he made them before 1609 or 1610. Antonius de Rheita, the inventor of the binocular telescope, in his *Oculus Enoch et Eliæ*, which appeared at Antwerp in 1645, fixes the date of Lapprey's invention in 1609, and states that, while holding a convex glass in one hand, and a concave one in the other, he accidentally combined them together. The claims of the Jansens are strongly corroborated by a letter from William Boreel, envoy of the states of Holland. This gentleman was intimately acquainted with Zachary Jansen, the son, had often played with him in his infancy, and was frequently in the shop of his father. He recollects having often heard that the Jansens were the inventors of the microscope; and when he was in England in 1619, he saw in the hands of his friend Cornelius Drebbel, the same microscope which the Jansens had given to the Archduke Albert, and which this Prince had presented to him. After giving a description of this instrument, which seems to have been a compound microscope, Boreel adds, that towards the year 1610 Jansen contrived a telescope; and that he had no sooner discovered the proper arrangement of lenses for this purpose, than he inclosed them in a tube, and ran with his instrument to Prince Maurice, who, conceiving that it would be of great use to him in his wars, desired him to keep it a secret. The invention, however, became known; and a stranger having come to Middleburg to seek the inventor, addressed himself to John Lapprey, whom he mistook for Jansen, on account of the proximity of their houses. The inquiries of the stranger led Lapprey to guess at the combination of lenses, and from this circumstance he was reputed the inventor of the telescope. The mistake, however, as Boreel informs us, was soon discovered; for Adrian Metius and Drebbel having come soon after this to Middleburg, went directly to Zachary Jansen, and purchased telescopes from him.

In the year 1609, when Galileo was at Venice, he received intelligence of the effect of the instrument presented by Jansen to Prince Maurice, but had no knowledge whatever of its construction. On the first night after his return to Padua he succeeded in solving the problem, and on the day following he constructed a telescope. This instrument, in a better form, he six days afterwards carried to Venice, and presented it to the doge, Leonardo Donati, who, in honour of his invention, gave him the ducal letters, which settled him for life in his lectureship at Padua, and doubled his salary. The following is Galileo's own account of the matter, as published in March, 1610, in his *Nuncius Sidereus*: "Near ten months ago, it was reported that a certain Dutchman had made a perspective, through which very distant objects appeared distinct as if they were near; several experiments were reported of this wonderful effect, which some believed, and others denied. But having it confirmed to me a few days after, by a letter from the noble James Badovere at Paris, I applied myself to consider the reason of it, and by what means I might contrive a like instrument, which I attained to soon after by the doctrine of refraction. And first I prepared a leaden tube, in whose extremities I fitted two spectacle glasses, both of them plain on one side, and on the other side one of them spherically convex and the other concave. Then applying my eye to the concave, I saw objects appear pretty large and pretty near me. They appeared three times nearer and nine times larger (in surface) than to the naked eye; and soon after I made another, which represented objects above sixty times larger; and at last, having spared no labour nor expense, I made an instrument so excellent as to show things almost 1000 times larger, and above 30 times nearer to the naked eye."

As the telescope invented by Jansen, and known by the name of the Galilean telescope, is suited principally for near objects, and has a very small field of view, philosophers soon attempted to improve the construction. Although no other telescope but this is described in the Dioptrics of Descartes, which was published in 1637, yet Kepler, in the 86th Prop. of his Dioptrics, which appeared in 1611, had explained the theory of the telescope, and had shown that a similar instrument might be constructed, by using one or more convex eye-glasses in place of the concave one. As one of these combinations, however, inverted the objects, and as Kepler does not seem to have been aware of the advantages which they possessed from the great enlargement of the field of view, Father Scheiner was the first who put in practice these suggestions of Kepler; and he has given an account of the performance of his telescope in the *Rosa Ursina*, which was published in 1650. These instruments received still farther improvement from Father Rheita, who introduced eye-pieces with three and four lenses, and thus completed the common refracting telescope.

Although Kepler is celebrated principally in the history of optics for his invention of the astronomical telescope, yet he had occasion to study with much care the subjects of refraction and of vision. He found that below 30° of incidence, the angle of refraction was nearly two-thirds of the angle of incidence; that when the angle of incidence was 90°, the angle of refraction in glass was 42° and some minutes; and that if the refracted ray fell with greater obliquity than 42° upon the interior surface, it would be totally reflected back into the glass at an angle equal to the angle of incidence. Having established these principles, he shows that plano-convex glasses have their focus for parallel rays at a distance from the lens, equal to the diameter of the sphere, of which their convexity is a portion, and that those which are equally convex on both sides have their focal distance equal to the radius of the same sphere. When the two surfaces are unequally convex, he determines their focal distance by taking a mean between the radii of the two spheres, of which the convexities form a part. The same reasoning he applies to concave lenses, with this difference only, that the focus is in this case between the lens and the radiant point. Kepler next endeavours to determine the focus of refracted rays, when the radiant point is at different distances from the lens. Having found that parallel rays unite in the focus of the lens as above determined, he shows that those which issue from this focus will emerge after refraction in parallel directions. If they radiate from a point between this focus and the lens, they will diverge after refraction, but their divergency will be diminished. Those rays which issue from a point beyond the focus, will converge after refraction; and when the distance of the radiant point is equal to twice the focal distance, the image will be formed at the same distance behind the glass.

The subject of vision is treated with great ingenuity by Kepler, in his *Astronomiæ Pars Optica*. He discovered that the images of external objects were painted on the retina by the union of the pencils of rays which issued from every point of them. He noticed also the inversion of these images; and he explained the manner in which long-sighted and short-sighted persons were enabled, by means of convex and concave lenses, to converge the pencils of rays to a focus upon the retina. He justly ascribed erect vision from an inverted image to an operation of the mind, by which it traces the rays back to the pupil, and thus refers the lower parts of the image to the upper side of the eye. Kepler considered it as beyond our powers to determine the manner in which the mind perceives the images of objects upon the retina. The power of accommodating the eye to different distances was carefully studied by this active philosopher; and, in order to explain it, he supposed that the contraction of the ciliary process drew the sides of the eye-ball towards the crystalline lens, and thus lengthened the eye, and withdrew the retina to a greater distance from the pupil, when the eye was adjusting itself to the vision of near objects.

It could not have been considered as an unusual step in the progress of science, if the accurate experiments of Ptolemy on refraction had been immediately followed by the discovery of its true law. It is rather singular, indeed, that Alhazen and Vitello should have overlooked it, and still more so that it should have eluded the acuteness and sagacity of Kepler. This important discovery was reserved for Willebrord Snellius, professor of mathematics at Leyden, who wrote a work on the subject, which was never published, having died at the early age of 35. The MS. of this work fell into the hands of Professor Hortensius, who explained the discovery both publicly and privately. In comparing together the refractions at different incidences, which he himself had determined by numerous experiments, Snellius observed that if the refracted ray, and the incident ray continued from the point of incidence, were intercepted by a line parallel to the perpendicular at the point of incidence, the length of the refracted ray bore a constant proportion to that of the incident ray continued. This proportion was that of 4 to 3 in water, and 3 to 2 in glass, whatever was the angle of incidence. Hence it follows, that the co-secants of the angles of incidence and refraction have a constant ratio.

Although no right to a scientific discovery was ever more clearly established than that of Snellius to the true law of refraction, yet it is strange that so respectable an author as Montucla should still appear desirous of ascribing some share of the discovery to his countryman Descartes. "If," says he, "we do not *precisely* owe to Descartes the first discovery of the law of refraction, we cannot at least refuse him the merit of having established upon this law the most curious geometrical researches." It is no doubt true, that Descartes, in his Dioptrics, published in 1637, eleven years after the death of Snellius, has announced it as a result of his own inquiries into the law of refraction, that the sines of the angles of incidence and refraction have a constant ratio, without taking the slightest notice of the discovery of Snellius, which had been made a considerable time before. Had Descartes distinctly said that he never heard of Snellius's law, we should not have disputed the declaration of such a distinguished character; but we are informed by Vossius, in his work *De Natura Lucis*, that the heirs of Professor Hortensius had freely communicated to Descartes the manuscripts of that professor, among which was that of Snellius's work; and this testimony is in a great degree confirmed by Huygens, who, in his remarks on refraction, prefixed to his Dioptrics, distinctly informs us that he himself had sometimes seen Snellius's MS. volume, and had heard that Descartes had also seen it.[*] Bossut has stated the case too strongly against Descartes, when he says that Huygens assures us that Descartes had seen the MS.

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[*] Hæc autem omnia quæ de refractionis inquisitione volumine integro Snellius exposuerat, inedita, mansere; *quæ et nos vidimus*

Huygens, however, when he saw the MS. more than once, must have seen it in the possession of Hortensius's heirs, who, no doubt, gave him sufficient evidence that it had been in the hands of Descartes. Although Montucla, however, has made this small reclamation in favour of his countryman Descartes, he nevertheless says, "that it was reserved for Snellius to make this important discovery, (viz. that of the true law of refraction,) to which he was probably conducted by the fruitless attempts which Kepler had made to find it,"[*] and has thus given to the Dutch philosopher the decided merit of being the original discoverer.[†] Bossut, another French author, also concurs in ascribing the honour of it to Snellius. In this decision he has been followed by Priestley, David Gregory, Muschenbroek, Smith, Robison, Playfair[‡], Hutton, Dr. Young; and, so far as we know, by all other optical writers. In looking into M. Biot's *Traité de Physique*, (tom. iii. p. 205,) we were in no slight degree surprised to find the discovery of the law of refraction ascribed *solely* to Descartes, and the name of SNELLIUS *never once mentioned*.[§] Had M. Biot defended his countryman from the charge of plagiarism, which is clearly implied in the opinions of Huygens, Bossut, and Playfair, and claimed for him the merit of a second discoverer, we might have applauded his zeal, and perhaps concurred in his decision; but when he sinks in oblivion not only the labours[‖] of Snellius, but also his very name, every generous feeling is roused in defence of the injured philosopher. There is something about the history and fate of Snellius, which might have protected him against any harsh treatment, and which will probably excite many sympathies in his favour. His discovery of the law of refraction was made in 1621, when he was scarcely thirty years old; and before he had enjoyed the high reputation to which he was thus entitled, he was cut off by a premature death, in the thirty-fifth year of his age. The manuscript volume which contained his numerous experiments on refraction, and the explanation of the law by which he generalized them, was never given to the world, but was unsuspectingly exhibited to the very individual for whom all his honours have been so unjustly claimed. Although Snellius was a good geometer, and published several works of considerable merit, yet his name has been emblazoned in the temple of science solely by his optical discovery; and philosophers of every country, and of every age, have gratefully paid their tribute of admiration at his youthful shrine. In a case like this, national prepossessions might well have yielded to a nobler sympathy, and even if the right of property had been ambiguous, the wreath which has crowned Descartes with immortality might have been allowed to spare one laurel for the brow of Snellius.

The Dioptrics of Descartes, though stained by the omission of the name of Snellius, added in a very high degree to the optical knowledge of the times. As lenses of a spherical form had been found not to converge parallel rays to one point, Descartes set himself to inquire if any surface existed, by which an accurate convergence to a single point might be effected. Kepler had already conjectured from analogy that the conic sections might have this property; but it was left to Descartes to complete the investigation. He solved the problem in a very general and elegant manner, and showed how this object could be accomplished by curves, which he called ovals, and which, in certain cases, particularly wanted in optical instruments, become ellipses and hyperbolas. Descartes could not fail to see the apparent advantages of this result; but, ignorant of the principal causes of the imperfections of telescopes, he expected much more from this discovery than it was capable of yielding. He immediately contrived machines for grinding elliptical and hyperbolical lenses, and when he was at Paris in the year 1628, he engaged a mathematical instrument maker of the name of Ferrier to enter into his views. This artist, after much labour, succeeded in completing a tolerably good hyperbolical convex lens, but he failed in the concave ones, and being disgusted with the difficulty of the work, he abandoned the undertaking. The hopes of Descartes, however, were not so easily subdued. Holding out the promise of discovering, by means of such lenses, the smallest objects in the stars, and assisted by the friendly instigation of M. Huygens, the father of the celebrated philosopher, he persuaded some Dutch artists to renew the unsuccessful attempts of Ferrier. The same difficulties, however, were expe-

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aliquando, et Cartesium quoque vidisse accepimus, ut hinc fortasse mensuram illam quæ in sinibus consistit, elicuerit; qua in explicanda Iride et Vitrorum figuris investigandis felicissime est usus."—*Dioptrica*, p. 3.

[*] "Il ètoit reservé à Snellius, mathematicien Hollandois, et recommandable à divers autres titres de faire cette importante decouverte, à laquelle il étoit probablement conduit par les efforts impuissans qu'avoit fait Kepler pour la trouver.—*Montucla*, tom. ii. p. 244.

[†] It is a remarkable fact, which seems to have escaped the notice of optical writers, till we pointed it out in the life of Gregory, that the law of refraction, in its most improved form, was discovered by our countryman, James Gregory, without any knowledge of what had been done by Descartes. He is therefore entitled to more honour than Descartes, for he never saw the MS. of Snellius.—*See* p. 602.

[‡] "There is no doubt, therefore," (says Mr. Playfair, the most candid and unprejudiced writer of any age or country,) "that the discovery was first made by Snellius; but whether Descartes derived it from him, or was himself the second discoverer, remains undecided. The question is one of those, where a man's conduct in a particular situation can only be rightly interpreted from his general character and behaviour. If Descartes had been uniformly fair and candid in his intercourse with others, one would have rejected with disdain a suspicion of the kind just mentioned. But the truth is, that he appears throughout a jealous and imperious man, always inclined to depress and conceal the merit of others. In speaking of the invention of the telescope, he has told minutely all that is due to accident, but has passed carefully over all that proceeded from design; and has incurred the reproach of relating the origin of that instrument without mentioning the name of Galileo. In the same manner, he omits to speak of the discoveries of Kepler, so nearly connected with his own; and, in treating of the rainbow, he has made no mention of Antonio de Dominis. It is impossible that this should not produce an unfavourable impression; and hence it is, that the warmest admirers of Descartes do not pretend that his conduct towards Snellius can be completely justified.

Descartes would have conceived his philosophy to be disgraced, if it had borrowed any general principle from experience; and he therefore derived, or affected to derive, the law of refraction from reasoning or from theory."—*Suppl. Encycl. Brit.* vol. ii. p. 101.

[§] "La decouverte de cette belle proprieté est due a Descartes," p. 204: and again, in p. 505, "Dont un seul (the ordinary ray) suit a loi decouverte par Descartes." The same sentiment is repeated in his *Précis Elementaire de Physique*, tom. ii. p. 114, where he goes still farther, and ascribes to Descartes the discovery, that the incident and refracted rays are always in the same plane, and perpendicular to the common surface of the two media. Even Ptolemy knew this, and it was most assuredly well known to Snellius

[‖] "*Multo labore, multisque experimentis*," says Huygens, "eo pervenit ut veras quidem refractionem mensuras teneret," &c.—*Diopt.* p. 2.

rienced, and, though succeeding philosophers have wasted their ingenuity in devising machines for the same purpose, elliptical and hyperbolical lenses have had no existence but in the theoretical writings of opticians; and there is some reason for doubting, if the reflecting telescope has derived much improvement from the attempts which are generally made to give a parabolic form to the great speculum. In perfecting the theory of the rainbow, the fine genius of Descartes shines with new lustre; and we wish it could have been added, that this lustre was not impaired by another act of selfish appropriation. Although Antonio de Dominis had observed and published the true principle of this theory, Descartes never even mentions his name; and, as in the case of the unfortunate Snellius, M. Biot has, in opposition to the decision of all ages, assisted Descartes in depriving the Italian prelate of the only discovery which has signalized his name. The exterior rainbow, which had baffled the ingenuity of preceding philosophers, received the most satisfactory explanation from Descartes. He shows that the rays of the sun entering the inferior part of the drop, and experiencing one refraction, suffered two reflections within, and then emerged by a second refraction. Hence he accounted for the inversion of the colours in the exterior bow, and the comparative faintness of its light. Descartes also explains, in a very satisfactory manner, why the interior bow has a diameter of 42°, and the exterior one of 52°, and he has done all that could be expected on this subject, previous to the great discovery of the different refrangibility of light. We owe also to Descartes a number of interesting observations on vision. His remarks on the method by which the eye judges of distances and magnitudes are ingenious, and sometimes sound; and he ascribed the adaptation of the eye to different distances to a change of curvature in the crystalline lens, which he supposed to be a muscle, having the ciliary processes for its tendons.

Scheiner, whose improvement on the telescope we have already had occasion to mention, added some important facts to the subject of vision. By cutting away the coats from the posterior part of the eyes of sheep and oxen, and holding several objects before them at the usual distance at which vision is performed, he saw the most distinct images of them beautifully painted on the naked retina. The same experiment he performed with the human eye, and exhibited it at Rome in the year 1625. This ingenious author notices the analogy between the eye and the camera obscura, and explains the erectness of the object from the inversion of the image, as Kepler had done, by stating that the mind traces the rays back to the pupil, and refers them to that part of the object from which they seem to have proceeded. The contraction of the pupil, when the eye examines near objects, was also well known to Scheiner; and many other curious, though less important, facts respecting vision through small apertures. He examined with considerable care the refracting powers of the humours of the eye; and he concludes that the aqueous humour has a refracting power differing little from water; that the refracting power of the crystalline humour differs little from glass, (in which he was greatly mistaken,) and that the vitreous humour has a refractive power, of an intermediate magnitude. He traces the progress of the rays through all the humours of the eye, and, after much judicious reasoning, he refutes the opinion, that the crystalline lens is the seat of vision; and establishes the doctrine, which, he says, was that of Alhazen, Vitello, and Kepler, that the retina is the true seat of vision.

Among the discoveries of this period, there is none more curious in itself, or more important in its consequences, than that of double refraction, which was made by Erasmus Bartholinus. Having obtained from some Danish merchants, who frequented Iceland, a "crystal stone, like a rhombic prism, which, when broken into small pieces, kept the same figure," and afterwards from its locality called *Iceland crystal;* he made many optical and chemical experiments with it, and discovered that it possessed the remarkable property of a double refraction. He found that one of those refractions, whose index was 1.667, was performed according to the law of Snellius, which is common to all transparent solids and fluids, while the other is performed according to an *extraordinary law*, which had not previously been observed by philosophers. An account of these experiments our author published at Copenhagen, in the year 1669, under the title of *Experimenta Crystalli Islandici Dis-diaclastici quibus mira et insolita refractio detegitur;* and he afterwards communicated an account of them to the Royal Society, in a letter to Dr. Oldenburg, which appeared in No. 67, of the *Philosophical Transactions.*[*]

In this new and interesting field of inquiry, Bartholinus was followed by Christian Huygens, a Dutch philosopher, one of the finest geniuses of the age in which he lived, and equally distinguished by his astronomical, his optical, his mathematical, and his horological discoveries. A few years after the publication of Bartholinus's work, the attention of this celebrated individual was directed to the subject of double refraction. He was induced to begin this investigation, principally, with the view of obviating any objection that might be drawn from the facts discovered by Bartholinus against his own theory of ordinary refraction; and he was led to the particular views which he has published, from a desire to assimilate the two classes of phenomena. His researches on this subject form the fifth chapter of his *Traité de la Lumiere*, which is entitled *De l'estrange refraction du Cristal d'Islande.* This work was composed about the year 1678, and read to several of the members of the Academy of Sciences, but it was not published till the year 1690, when Huygens was resident in Holland. After describing the general appearances exhibited by Iceland spar, he shows that all the phenomena are related to the short diagonal, or axis of the rhomb, along which the double refraction is nothing; that it gradually increases, according to a law which he explains, as the inclination of the refracted ray to the axis increases, and becomes a maximum when that inclination is 90°. He then proceeds to explain his theory of double refraction, founded on the hypothesis of light being the undulation of an ethereal medium, by which he had already given an elegant explanation of all the phenomena of refraction and reflexion. He supposes the ordinary refraction to be produced by spherical undulations propagated through the crystal, while the extraordinary refraction arises from spheroidal undulations, the form of the generating ellipse being determined by the ratio of the two refractions. He then proceeds to show that the deviation of the extraordinary ray, calculated upon this hypothesis, agrees precisely with observation.

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[*] See the *Edinburgh Philosophical Journal,* vol. i. p. 271, for a full account of Bartholinus's experiments.

After he had drawn up his treatise on double refraction, Huygens discovered what he calls a "wonderful phenomenon," or the polarization of the two pencils of light formed by Iceland spar. Hitherto he had supposed the light to have the same properties as any other ordinary light; but upon transmitting the two pencils formed by one piece of Iceland spar through another piece, he was surprised to observe, that when the two pieces were similarly placed, or with their *principal sections* parallel, neither of the two pencils were divided in passing through the second rhomb, the pencil which had suffered the ordinary refraction by the first rhomb being only ordinarily refracted by the second, and the pencil which had been extraordinarily refracted by the first being only extraordinarily refracted by the second rhomb. He found also, that when the principal sections cut one another at right angles, the ray which was ordinarily refracted by the first crystal suffered only the extraordinary refraction from the second; and the ray which suffered the extraordinary refraction from the first suffered only the ordinary refraction from the second. But in all other positions of the principal sections, excepting these two, the rays divided themselves into two, by the refraction of the second crystal, so that from the single pencil of light incident on the first crystal, there were formed four pencils, sometimes of equal brightness, according to the different positions of the crystals, but which did not seem to have more light, when taken altogether, than the single ray. Huygens acknowledged himself unable to form any satisfactory conjecture respecting the nature or cause of this new property of light; and it was reserved for Newton to show, that the sides of the rays had, in passing through the first crystal, acquired different properties.

Notwithstanding the great accuracy of Huygens's law of double refraction in Iceland spar, he never supposes that it was a general law for all other bodies. He maintains, on the contrary, that he had found by direct experiment, that the only other doubly refracting crystal with which he was acquainted, namely, rock crystal, had its double refraction regulated by an entirely different law, the light being *propagated through it in two spherical waves*, one of which was a little slower than the other. This result was obtained by cutting prisms of rock crystal in different directions, and is mentioned in his preface as a new remark, which he had made after the first copy of his treatise had been communicated to some of the members of the Academy of Sciences. Huygens, therefore, proposed two different laws of double refraction, the one for Iceland spar, and the other for rock-crystal. The last of these, founded on incorrect observations, has no existence in nature, while the first represents the phenomena of Iceland spar, within the limits of the errors of observation.*

The optical labours of Huygens were not limited to the subject of double refraction. His treatise on Dioptrics, which he began to compose in the early part of his life, but which was not published till after his death, is a work of transcendent merit, and was always especially admired by Newton himself. It contains a full account of the properties of lenses of all forms. The doctrine of spherical aberration, or that which arises from the spherical figure of the surface, is treated with great clearness and ability. The subject of vision, and the remedy of its imperfections by lenses, is ably handled; and the theory of telescopes, telescopic eye-pieces, and microscopes, is treated with fulness and perspicuity. The imperfect state of the telescope induced Huygens to extend his views beyond the mere theory of its construction. He employed himself in executing the lenses with his own hands; and by means of telescopes of 12 and 24 feet in focal length, which he himself made, he discovered the ring of Saturn, and the fourth of the satellites of that planet. Telescopes of the focal length of 86, 100, and 136 feet, had been made by Campani of Bologna, by which Cassini discovered the nearest satellites of Saturn; and Eustachio Divini, of Rome, had also constructed them of a great focal length. Huygens, however, made essential improvements in the method of using an object glass without a tube, which it was necessary to adopt in instruments of such extreme length. He placed the object glass in a short tube, at the top of a very long pole, so that this tube could turn in every direction by means of a ball and socket. The command of this tube at a distance was obtained by means of a silk string, so that he could bring it into a line with the axis of another short tube, containing the eye-glass, which he held in his hand. By this means he could direct his object glass in any azimuth, or to any altitude, and even to the zenith, if the pole were as long as the telescope. For this purpose he had a contrivance, by which he could raise or depress a stage that supported his object-glass. In this way Huygens used telescopes of enormous length; and in one of his journies to England, he presented to the Royal Society two object glasses, one of which had a focal length of 120, and the other of 123 feet.

Having acquired great experience in the art of constructing telescopes, this eminent philosopher thought it right to transmit his methods to posterity, in a work published along with his Dioptrics, and entitled *Commentarii de formandis poliendisque vitris ad Telescopia.* In this work he treats of the method of forming the gages, and the brass tools or moulds; of the method of choosing proper glass; of the grinding and smoothing of the lens, and the method of giving it a perfect polish.

Along with this work appeared his *Dissertatio de Coronis et Parheliis*, a treatise of great ingenuity, in which he endeavours to give the theory of these curious and hitherto unexplained phenomena.

We cannot conclude this account of the optical labours of Huygens, without noticing his theory of light, which he has explained at great length in his *Traité de la Lumiere* already mentioned. This treatise is divided into six chapters, the first of which treats of light propagated directly; the second of reflexion; the third of refraction; the fourth of the refraction of the air; the fifth of Iceland crystal; the sixth of the figures of transparent bodies, for the purposes of refraction and reflexion. The fifth chapter occupies nearly one half of the treatise; but in the first chapter he explains his theory of light, which he supposes to be produced in the same manner as sound, by undulations propagated in an elastic ethereal medium; and he shows how, by this principle, all the phenomena of refraction and re-

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[*] A very full account of Huygens's discoveries will be found in the *Edinburgh Philosophical Journal*, vol. ii. p. 167—171; and vol. iii. p. 277—286.

flexion may be produced. This hypothesis was afterwards revived by the celebrated Euler, and ably defended and illustrated by our countryman Dr. Thomas Young. The law of interference, discovered by this distinguished philosopher, and other recent discoveries, have drawn to it the attention of many eminent modern philosophers, and have gained for it a degree of support which threatens to overwhelm the Newtonian doctrine of emission.

While the sciences of optics and astronomy were advancing hand in hand on the continent, in consequence of the improvements which were making on the refracting telescope, our countryman James Gregory enriched the science, by his invention of the reflecting telescope, which is described at the end of his *Optica Promota*, published in 1663. It consisted of a parabolic concave mirror, perforated at the centre, in front of which was placed a small concave elliptic speculum, at a distance a little greater than the sum of their focal lengths. The parallel rays issuing from a distant object formed an image in front of the great mirror, in its focus; and this image, serving as another object, had an image of itself formed behind the great mirror, by the small one, by means of rays passing through the perforation in its centre. This image was then viewed with an eye-glass. The invention of this instrument was followed, in 1666, by the Newtonian telescope, which consisted of an unperforated mirror, that threw the image of the object upon a small plane speculum, placed at an angle of 45° within its focus, so as to reflect the image aside to the eye of the observer, where it was viewed with an eye-glass. About the year 1672, M. Cassegrain gave a new form to the reflecting telescope, by using a convex small speculum, placed nearer the great speculum than its principal focus. The effect of this change was to shorten the telescope; and there is reason to think that this instrument gives more perfect vision than those of either the Gregorian or Newtonian form.

As is the case with all remarkable inventions, Gregory has not been allowed to maintain the undisturbed possession of the honour of having invented the reflecting telescope. Father Mersenne,* in a correspondence with Descartes† in 1639, but which was not printed till 1666, three years after the appearance of the *Optica Promota*, *proposed* to Descartes the idea of using concave mirrors in the construction of telescopes; but, so far from having invented and constructed an instrument of value, Descartes endeavoured to convince him of the fallacy of his views. Another claimant for the same honour was brought forward by Fontenelle, who, in his history of the Academy of Sciences for 1700, has ventured to say, "that the reflecting telescope was begun to be used as early as the year 1616." "Father Zucchi," he continues, "an Italian Jesuit, in his *Optica Philosophia*, printed at Lyons in 1652, says, that in 1616, reflecting on the theory of telescopes then recently invented, it came into his head to *employ concave metallic mirrors, instead of object lenses of glass*, in order to produce by reflexion the same effects which result from refraction. Having found, therefore, in a cabinet of curiosities, a concave metallic mirror, exactly worked by an able artist, he applied to it a concave eye-glass, and with this telescope observed terrestrial and celestial objects; and experience confirmed what theory had taught him."‡ We need scarcely appeal to the candour of the reader for his decision upon this claim. Zucchi obviously made an experiment with a concave mirror and a concave lens, in the same manner as we have reason to believe was done by Roger Bacon and Leonard Digges. As there was no small speculum, the telescope was neither Gregorian, Newtonian, nor Cassegrainian; and can be considered in no other light than a rude and imperfect experiment by oblique reflexion, which must have distorted and spoiled the image, even if his speculum had possessed a true figure. Had Zucchi told us the focal length of his mirror, we might probably have found it to be so short, that the idea of calling the experiment a telescope, might have been still more ridiculous than it appears to be, when we are left to form any notion we please of the magnitude and focal distance of the speculum. If Zucchi had conceived himself the inventor of the reflecting telescope, why did he remain contented with a mirror found by accident in a cabinet of curiosities? He must have thought his experiment useless, otherwise he would not have failed to improve it by the addition of a tube, and the application of a small speculum.

The reputation of James Gregory, however, was not confined to the invention of the telescope. He had also the high honour of discovering the law of refraction in its most improved form, as we have already stated in our account of his life. By comparing the tables of refraction in Vitello's optics, and those given by Athanasius Kircher, he was led to the discovery of the constant ratio of the sines. By comparing this law with Vitello and Kircher's experiments, he found the greatest deviation to be 1° 29′ in water, 1° 50′ in wine, 1° 44′ in oil, and 1° 33′ in glass; but by comparing it with a series of observations made by himself on the refractive powers of all these substances, he found the greatest error to be only 15′. Vitello made the refractive power of water 1.306, whereas Gregory found it to be 1.3347, within 0.0018 of the most accurate measure that has yet been published. Gregory learned before the publication of his work, that he had been anticipated by Descartes in this discovery, and he ascribes his ignorance of Descartes's Dioptrics to the "want of new mathematical books in the otherwise celebrated library of Aberdeen"

Among the optical writers of the present period, was Francis Maria Grimaldi, a learned Italian Jesuit, who, along with his friend Riccioli, cultivated the sciences with much ardour. He is principally distinguished for his discovery of the *inflexion*, or the *diffraction of light*, as he called it, of which he published an account in his *Phisico-mathesis de Lumine, Coloribus et Iride, aliisque annexis*, lib ii. which appeared in 1665, at Bologna, after his death. Having admitted a ray of light into a dark room by a very small aperture, he observed that it was diffused in the form of a cone, and that all bodies placed in this divergent light, had their shadows larger than they should have been, had the light passed in straight lines by their edges. Upon more mature observation, he discovered that the shadow was surrounded by three coloured fringes, growing narrower as they receded from the body; and, when the light was strong, he perceived similar coloured streaks within the shadow, which sometimes were only two in number, and sometimes four, the number increasing in the same shadow when it was received at a greater distance from the body. From these new and important facts, Grimaldi concluded that light is bent from its rectilineal direction in passing by the edges of bodies. By admitting into a dark chamber two cones of light through apertures placed so near one another, that the one cone did not penetrate the other, till at a considerable distance from the aperture, Grimaldi observed that the mutual interferences of the rays influence one another, in such a manner as to render the spot illuminated by their joint incidence more obscure than when it was illuminated by either of them singly. This remarkable result is separately announced in the proposition, "that a body actually illuminated may become more obscure by adding a new light to that which it already receives." Grimaldi had likewise the merit of first observing the fact, that the solar image was lengthened by the refraction of the prism; but he was entirely ignorant of the different refrangibility of light. See the article GRIMALDI.

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* In Mersennes' Catoptrics, prop. 7th, which appeared in 1651, a similar idea is stated. Montucla has very properly said, "that Mersenne augured some degree of perfection for telescopes, from the use of reflecting mirrors."

† Lettres, tom ii. lett. 29 and 32.

‡ Fontenelle does not seem to have seen the *Optica Promota*, or known its date, as he states that Newton's telescope was invented before Gregory's.

Our ingenious countryman, Dr. Hooke, made nearly the same discovery with Grimaldi respecting the inflexion of light, without knowing what had been done by the Italian philosopher. He communicated his observations to the Royal Society, in 1672, six years after the appearance of Grimaldi's work; and he speaks of his paper as containing "the discovery of a new property of light not mentioned by any optical writers before him." In another paper, read to the same learned body in 1675, he draws the following conclusions from his experiments, some of which, but particularly the last, have acquired no inconsiderable interest from the investigations of subsequent authors.

1. There is a *deflection* of light, differing both from reflexion and refraction, and seeming to depend on the unequal density of the constituent parts of the ray, whereby the light is dispersed from the place of condensation, and rarefied, or gradually diverged into a quadrant. 2. This deflection is made towards the superficies of the opaque body perpendicularly. 3. Those parts of the diverged radiations, which are deflected by the greatest angle from the straight or direct radiation, are the faintest, and those that are deflected by the least angles are the strongest. 4 Rays cutting each other in one common foramen do not make the angles at the vertex equal. 5. Colours may be mado without refraction. 6. The diameter of the sun cannot be taken with common sights. 7. The same rays of light, falling upon the same point of an object, will turn into all sorts of colours by the various inclination of the object. 8. Colours begin to appear when two pulses of light are blended so well, and so near together that the sense takes them for one.

One of the greatest optical and astronomical discoveries of the 17th century, was that of the successive propagation of light, and the velocity with which it moves in absolute space. This interesting truth, which was one of the best results of the invention of the telescope, was obtained by the Danish astronomer Olaus Roemer. Galileo, and after him the Academy del Cimento, had in vain attempted to measure the speed of this fleet element. While examining some singular irregularities in the emersion of the first satellite of Jupiter, on the 9th November, 1676, Cassini and Roemer concluded that it depended on the distance of Jupiter from the earth, and that it was necessary for its explanation, to suppose that the light of the satellite spent about ten or eleven minutes in crossing the orbit of the earth. Cassini, however, who seems to have first started this hypothetical opinion, speedily abandoned it; but the notion was keenly maintained by Roemer, who finally succeeded in demonstrating, to the satisfaction of all philosophers, that light moved through the diameter of the earth's orbit, or about 190 millions of miles in eleven minutes.

Among the distinguished optical writers of the present period was Walter Ernfroy Tschirnhausen, lord of Killingswald and Stolzenberg, in Lusatia in Saxony. After serving as a volunteer in the Dutch army, in 1672, he travelled through England, France, Italy, and Germany, and having visited Paris for the third time in 1682, he communicated to the Academy of Sciences his discovery of caustic curves, formed by the refraction or reflexion of parallel rays falling upon a curved surface, in consequence of the intersection of the refracted or reflected rays at points not coincident with the geometrical focus of the refracting or reflecting body. These curves must have been seen by every person at the bottom of a polished cylindrical vessel, upon the inner surface of which the rays of the sun or of a candle are incident. In the Memoirs of the Academy for 1682, Tschirnhausen published his first views on the subject, and accompanied them with the delineation of the caustic of a circle formed by incident rays that were parallel. M. De la Hire pointed out some mistakes in this paper, which led to a dispute with its author. This curious subject was afterwards studied by James and John Bernoulli, who extended the theory to converging and diverging rays; and by M. Bouguer, who discovered the double caustic, formed at the same time by convex and concave surfaces. Being the proprietor of extensive glass-works, Tschirnhausen availed himself of the opportunity which was thus afforded him of constructing large burning glasses, of which we have given a very particular account in our article on BURNING INSTRUMENTS, vol. v. p. 140.

Tschirnhausen seems to have been the first person who successfully employed a large object lens as a telescope, with no other eye-glass but the eye of the observer. Baptista Porta, Scheiner, and Manfredi Septala of Milan, had no doubt made the same experiment; but it was left to the Saxon philosopher to carry the idea into actual use. With a double convex object glass $12\frac{4}{10}$th inches in diameter, and 32 feet long, he saw very distinctly at Nuremberg a whole town about six English miles distant; the vision was uncommonly distinct, the light great, and the field of view unusually large. Tschirnhausen had also the merit of establishing in Saxony that porcelain manufacture for which it has so long been celebrated.

About this period a number of very interesting discoveries relating to vision were made by some ingenious French philosophers. M. Petit, who devoted much attention to the structure of the eyes of animals, discovered that the crystalline lens was nearly spherical in serpents and fishes, while in other animals it was lenticular, the anterior having a greater convexity than the posterior surface. In all animals the crystalline lens grows firmer with age. It has different degrees of hardness in different animals; and in fishes the anterior nucleus is nearly as hard as horn,—a structure which Dr. Porterfield afterwards found to be necessary for converging to the same focus the rays that passed through the axis, and the margin of the lens. M. Petit observed, that after the age of 25, the human crystalline lens begins to be yellowish at the centre, and that this tinge, which continually grows deeper, gradually extends farther and farther towards its circumference. Two lenses of a person 81 years of age resembled two pieces of beautiful yellow amber. The imperfection of vision which was found to exist in children, he found to be owing to the thickness of the cornea, and the small quantity of their aqueous humour; a result which was obtained also with the eyes of new born animals, such as dogs, cats, rabbits, calves, and hogs. In order to illustrate the phenomena of vision, the construction of an artificial eye was proposed by Huygens. The structure of the crystalline lens of animals had been previously investigated with much success by the celebrated Leeuenhoek. He found, that when dry it consisted of many thin concentric laminæ or scales; and he maintains that these laminæ are all made up of one single fibre or fine thread, wound up in a most curious manner, so as to pass several courses, and meet in as many centres, and yet not interfere or cross one another in any place. In oxen, sheep, hogs, dogs, and cats, the fibre spreads itself in three different courses, and forms as many centres; while in whales it has five, and in hares and rabbits only two.

Hitherto it had been imagined, that the delicate, transparent, and reticulated membrane at the bottom of the eye, called the *retina*, was the seat of vision, or the ground upon which all the pencils of light were converged, in order to produce vision. The circumstance of its being an expansion of the optic nerve, and of its succeeding the transparent humours of the eye, rendered this opinion very probable. Having found, however, that the part of the retina at the insertion of the optic nerve is insensible to the impression of light, Mariotte was led to entertain the opinion, that the *choroid coat*, situated behind the retina, was the seat of vision.* In order to observe this fact, he directs us to place on a dark ground two round pieces of white paper at the same height, and three feet from one another; then to stand opposite to them at the distance of twelve or thirteen feet, and hold the thumb before the eyes at the distance of about eight inches, till it conceal from the right eye the paper that is to the left hand, and from the left eye the paper that is to the right hand. By looking at the thumb steadily with both eyes, the observer will lose sight of both the papers, the eyes being placed in such a manner that each of them receives the image of one of the pieces of paper upon the base of the optic nerve, while the other is intercepted by the thumb. This interesting experiment may be performed in a more elegant manner, by fastening three pieces of paper, A, B, C, about two feet apart, upon the wall of a room. The observer placing himself opposite, and pretty near, the middle one B, must retire gradually from it, keeping all the time one of his eyes shut, and the other turned obliquely towards A if the left eye is covered, or towards C if the right eye is covered, and he will find a situation, commonly about five times the distance at which the papers are placed, where the paper B will entirely disappear, while A and C continue visible. In this position the image of B falls upon the base of the optic nerve. The transparency of the retina occurred to Mariotte as another argument against the retina being the seat of vision, as he could not conceive the pencils to terminate upon a transparent ground. The dark colour of the choroid coat, and the circumstance of the pupil, which is extremely sensible to light, being an expansion of it, appeared to M. Mariotte additional arguments in favour of his hypothesis. To these arguments we may add another, drawn from the existence of the *foramen centrale*, which Soemmering discovered in the very centre of the human retina. If in the living subject this aperture is actually open, as it appears to be in the dead one, then we should expect to see a dark spot along the axis of vision, or on the very point of every object where vision is most perfect. This circumstance has recently led Dr. Macdonald to suppose, that the existence of this aperture is the cause of vision being most distinct when the image is received on that part of the eye, in consequence of the rays arriving without obstruction at the choroid coat. M. Pecquet, M. De la Hire, and M. Perrault, took up the same arguments in favour of the retina being the seat of vision; while the doctrine of Mariotte was supported by M. Le Cat, M. Mery, and by our countrymen Mr. Michell and Dr. Priestley. M. De la Hire, however, saw the difficulties of the ordinary hypothesis, and adopted the intermediate opinion, that the choroid coat receives the impression of images in order to transmit them to the retina. Notwithstanding the force of the arguments urged by Mariotte, and particularly by Mr. Michell, that which is derived from the transparency of the retina appears to us entirely without weight. If there was another eye behind the retina, which looked at the picture formed upon it, as in a camera obscura, then the transparency of the retina would undoubtedly render the image faint and indistinct; but the formation of a perfect picture upon the retina visible to an eye behind or before it, is by no means necessary to the transference of the sensation to the brain. It is enough for the purposes of vision, that the retina is excited by pencils accurately convergent upon its delicate fibres; and, for any thing we know to the contrary, the transparency of the retina, as the recipient of the convergent pencils, may be absolutely necessary to prevent it from being injured by the detention and absorption of light or heat.

The science of optics was now destined to receive an accession of the finest discoveries from the genius of the illustrious Newton. In the year 1664, when he was only in the 24th year of his age, he purchased a glass prism for the purpose of examining experimentally Descartes's doctrine of colours. During that and the subsequent year, he amused himself in grinding lenses of an elliptical and hyperbolic form, in order to correct the imperfection of figure, which was then believed to be the only obstacle to the perfection of the telescope. Unsuccessful, however, in this attempt, he thought of repeating Grimaldi's experiments on the lengthening of the sun's image by the prism. The brilliancy of the colours, and the oblong figure of the spectrum, which he at first supposed to be accidental, struck him with surprise, and attached an interest to the investigation which induced him to prosecute the subject with all the ardour of his mind. In examining the solar image, Newton found that its elongation arose from the different refrangibility of the different rays or colours which it contained. He saw that each separate colour had a constant refrangibility, which was not altered by the prism; or that in every refracting substance there was a certain ratio of the sines, which was different for different colours, but constant for the same colour. Hence he concluded, that the white light incident on his prism was a heterogeneous mixture of various homogeneous rays possessing different refrangibilities; and he succeeded in recomposing white light out of its gaudy elements, and thus completing the proof of its composite character. No sooner had Newton established these opinions, than he saw the cause of the imperfections of the refracting telescope, and, computing the error which arises from the different refrangibility of light in a given object glass, he found it to be about 1200 times that which arises from its spherical figure. Had elliptical and hyperbolical lenses, therefore, been as easily ground as spherical ones, the telescope would have experienced from this cause scarcely any perceptible improvement. Hence Newton was forced to have recourse to the principle of reflexion for the construction of these instruments; and he began with his own hands to grind and polish concave metallic mirrors. In this way he constructed two reflecting telescopes, of the kind since called Newtonian, which he found to surpass refracting telescopes in distinctness and power. On the 11th January, 1672, the day of his election as a Fellow of the Royal Society, he sent to that learned body one of his reflecting telescopes, which was publicly exhibited at their meeting. The approbation which this instrument seems to have received, excited a feeling of high satisfaction in the mind of its author; and in a letter written to Mr Oldenburgh, in the following week, he announces his intention of communicating a "philosophical discovery which induced him to the making of the same telescope, and which," he continues, "I doubt not, will prove much more grateful than the communication of that instrument, being in my judgment the *oddest, if not the most considerable detection which hath hitherto been made in the operations of nature.*" The "considerable detection" here alluded to, which was that of the different refrangibility of light, was laid before the Society on the 8th February. It was received with peculiar applause, and the papers ordered to be immediately printed. This great discovery, which not only led to the invention of the Newtonian telescope, but also to the completion of the theory of the rainbow, was received abroad with a degree of opposition, which national and personal jealousy seem to have in some degree inspired. A herd of perishable names sustained for a while an attack upon doctrines which they did not understand; and after having wounded the feelings, and disturbed the serenity of that great mind which had conferred on science the noblest of her gifts, the Newtonian theory of light and colours was triumphantly adopted throughout all Europe.

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* *Observations sur l'Organe de la Vision*, Mem. Acad. 1666, tom. i. p. 68.

The attention of Newton was next directed to the colours of thin transparent bodies, which had been observed, and to a certain degree studied, both by Boyle and Dr. Hooke, and in this department of optics his genius was equally triumphant. On the 16th Sept. 1675, he communicated to the Royal Society his paper "On the principal phenomena of the various colours exhibited by thin plates or bubbles." This paper led to a controversy with Dr. Hooke, who claimed a prior right to the discovery; but Newton was too firm to yield to his irascible rival; and he succeeded in satisfying the Society, not only that "the two main experiments were unknown to Mr. Hooke," but "that he explained every thing in a way so differing from Mr. Hooke, that the experiments he grounds his discourse upon destroy all that Mr. Hooke saith about them."

On the 20th Jan. 1676, after Newton's answer to Dr. Hooke was read, another paper of this eminent philosopher was laid before the Society, containing his "Theory of the Colours of Natural Bodies," which he declined to publish till he had perfected it by some additional experiments and observations. This theory was founded on the analogy which Newton supposed to exist between the colours of thin plates and the permanent colours of natural bodies. He had already shown, that bodies appear of different colours accordingly as they are disposed to reflect most copiously the rays originally endued with these colours; and he proceeds in the third part of the second book of his Optics, to point out the constitutions of bodies, in virtue of which they are disposed to reflect some rays more copiously than others. In doing this, he first shows that the least parts of all natural bodies, even the metals themselves, are transparent; that their opacities arise from the multitude of reflections caused in their internal parts; and he proceeds to demonstrate, "that the transparent parts of bodies, according to their several sizes, reflect rays of one colour, and transmit those of another, on the same grounds that thin plates or bubbles do reflect or transmit those rays;" and this he takes to be the cause of all that variety of colour which nature exhibits.

In order to account for the general phenomena of thin plates, and the partial reflection and refraction of light incident upon transparent surfaces, Newton devised the celebrated theory of fits of easy reflection and transmission, which, though it has often been ridiculed by those who could not follow the train of his reasoning, will ever be considered as one of the finest specimens of generalization. In this theory he considers every ray of light, in its passage through any refracting surface, as put into a certain transient constitution or state, which, in the progress of the ray, returns at equal intervals, and disposes the ray at every return to be easily transmitted through the next refracting surface, and between the returns to be easily reflected by it. What kind of action or disposition this is, our author does not pretend to determine, though he states the possibility of its consisting in a circulating or vibratory motion, either of the ray or of the medium. After explaining the way in which it may be produced by a vibration in the refracting medium, he remarks, that whether this hypothesis be true or false he does not mean to consider, but contents himself with the bare discovery, that the rays of light are, by some cause or other, alternately disposed to be reflected or refracted for many vicissitudes.

In the prosecution of his experiments on thin plates, Newton discovered a new set of phenomena, produced by thick transparent polished plates, which he has fully described in the fourth part of the second book of his Optics. These phenomena were analogous to those of thin plates, and are referred by Newton to the same general principles.

The subject of the inflection of light, begun by Grimaldi, was prosecuted with great success by Newton; though, in consequence of having been interrupted in his experiments, he left the investigation incomplete. His observations on this subject form the first part of the third book of his Optics, and it appears, from the queries which he has added to it, that he regards the phenomena of inflection as produced by the action of bodies on the passing light; that he considers the colours of the fringes as arising from the different flexibilities of the differently coloured rays, and that the three fringes arise from three bendings, resembling the motion of an eel.

The experiments of Newton on the refractive powers of bodies possess a high degree of interest. Air had the least refractive power, and diamond the greatest of all the bodies which he examined; but upon calculating their absolute refractive power, or that which was taken in relation to their densities, it appeared that sulphate of barytes (called by Newton *Pseudo-topaz*) had the least, and diamond the greatest. The most remarkable result, however, which he obtained, related to the refractive power of inflammable bodies, all of which had nearly the same absolute power, and one much higher than other bodies. "The refraction of camphire," says he, "oil-olive, linseed oil, spirit of turpentine, and amber, which are fat, sulphurous, unctuous bodies, and a diamond, which probably is an unctuous substance coagulated, have their refractive powers in proportion to one another as their densities, without any considerable variation. But the refractive powers of these unctuous substances, are two or three times greater in respect of their densities, than the refractive powers of the former substances, in respect of theirs."—"Whence it seems rational to attribute the refractive power of all bodies, chiefly, if not wholly, to the sulphurous parts with which they abound. For it is probable that all bodies abound more or less with sulphur." After these speculations, it is not a little remarkable that Newton never examined the refractive power either of sulphur or phosphorus, and thus missed the opportunity of confirming and extending those interesting views which have received such a remarkable confirmation from the discoveries of modern chemistry.

The only other branch of optics which Newton seems to have investigated, was that of double refraction and polarisation; but in this inquiry his usual genius seems to have forsaken him. Although he remarks that Huygens has described the phenomena of double refraction more exactly than Bartholinus, and therefore gives us reason to believe that he made some experiments on the subject, which confirmed those of the Dutch philosopher, yet it is unaccountable that, without assigning any reasons, or alleging any experimental results, he should reject Huygens's law, and substitute another, entirely inconsistent, not only with the experiments he has praised, but with those of all succeeding philosophers. In his speculations respecting the cause of the reappearance and disappearance of the pencils, when light is transmitted through two rhombs of calcareous spar, Newton has been more fortunate. He infers that every ray of light has two opposite sides, originally endowed with a property on which the unusual refraction depends, while the other two opposite sides are not endowed with that property, and he had, therefore, the undoubted merit of having first suggested the idea of the *polarity* of light.

In reviewing the optical labours of our immortal countryman, we cannot avoid hazarding some observations on the conclusion which Newton has drawn respecting the prismatic spectrum. These observations relate to two points. 1. The length of the spectrum produced by different refracting bodies; and, 2. The colours of which it is composed. 1st, There is perhaps in the history of science nothing more remarkable than that Newton should have believed that all bodies produced prismatic spectra of equal lengths. Although he had formed the spectra with water, and with different kinds of glass, and had used prisms of various substances, all of which differed prodigiously in their powers of separating the solar beam into its coloured elements, yet he never suspected that such a difference existed. Had he accidentally formed the glass parallelopiped, which he so often used, of two kinds of glass, he would have instantly made the discovery, and the invention of the achromatic telescope would have immediately followed it.[*] That acute and searching intellect, however, whose powers of analysis and combination were almost more than mortal, seems on this occasion to have lost its energy, and to have overlooked inquiries which were almost pressing themselves upon its notice.[†] Newton, indeed, had risen to more than his full share of reputation, and, lest the balance of scientific fame should be too much destroyed in the republic of letters, the discovery of refraction without colour was perhaps wisely left to adorn and astonish a future age. 2d, In his observations on the prismatic spectrum, Newton describes the different colours which enter into its composition; he gives measures of the spaces which they respectively occupy, and represents all the *seven colours* as homogeneous, and incapable of being decomposed. Had other two observers, one situated in Mercury, and the other in Jupiter, studied the prismatic spectrum of the sun by the same instruments, and with the same sagacity as Newton, it is demonstrable that they would have obtained very different results. On account of the apparent magnitude of the sun in Mercury, the observer there would obtain a spectrum entirely without *green*, having *red*, *orange*, and *yellow* at one end, the *white* in the middle, and terminated at the other end with *blue* and *violet*. The observer in Jupiter would, on the contrary, have obtained a spectrum, in which the colours were much more condensed, and from which the yellow was totally excluded, as in the spectrum from a narrow aperture, first described by Dr. Wollaston. On the planet Saturn, a spectrum exactly similar would have been obtained, notwithstanding the greater diminution of the sun's apparent diameter. It may now be asked, which of all these spectra are we to consider as exhibiting the number, and arrangement, and extent of the coloured spaces proper to be adopted as the true analysis of a solar ray? The spectrum observed by Newton has surely no claim to our notice, merely because it was observed upon the surface of the Earth. The spectrum obtained in Mercury affords no analysis at all of the incident beam, the colours being almost all compound, and not homogeneous, and that of Newton is liable to the same objection. Had Newton examined his spectrum under the very same circumstances in winter and in summer, he would have found the analysis of the beam more complete in summer, on account of the diminution of the sun's diameter; and, therefore, we are entitled to say, that neither the number nor the extent of the coloured spaces, as given by Newton, are those which belong to homogeneous and uncompounded light. The spectrum obtained in Jupiter and Saturn is the only one where the analysis is complete, as it is incapable of having its character altered by any farther diminution of the sun's diameter. Hence we are forced to conclude, not only that the number and extent of the primitive homogeneous colours, as given by Newton, are incorrect; but that, if he had attempted to analyse some of the primitive tints in his spectrum, he would have found them decidedly composed of heterogeneous rays. There is one consequence of these observations which is somewhat interesting. A rainbow formed in summer, when the sun's diameter is least, must have its colours more condensed and homogeneous than in winter, when the size of its disk is a maximum, and when the upper or the under limb of the sun is eclipsed, a rainbow formed at that time will lose entirely the yellow rays, and have the green and the red in perfect contact. For the same reason a rainbow formed in Venus and Mercury will be destitute of green rays, and have a brilliant bow of white light separating two coloured arches, while in Mars, Jupiter, Saturn, and the Georgian planet, the bow will exhibit only four homogeneous colours.

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[*] The moment Newton discovered the different refrangibility of light, he seems to have abandoned all hopes of improving the refracting telescope. He never even seems to have thought that there were any circumstances under which the evil of dispersion could be remedied; and hence his successors never ventured to repeat experiments which he had been correcting and revising during the last fifty years of his life.—See the Life of NEWTON, in vol. xiv. p. 484, and his *Optics*, Prop. vii. Book i. p. 91, where he distinctly says, that "*the improvement of telescopes of given lengths by refractions is desperate.*"

[†] A passage in one of Newton's letters to Oldenburgh, however, gives us reason for believing that he even tried the dispersive power of different media.—"Mr. Hooke," says he, "thinks himself concerned to reprehend me for laying aside the thoughts of improving optics by refraction. What I said there was in respect of telescopes of the ordinary construction, signifying that their improvement is not to be expected from the well-figuring of glasses, as opticians have imagined. But I despaired not of their improvement by other constructions, which made me cautious to insert nothing that intimates the contrary. For although successive refractions, which are all made the same way, do necessarily more and more augment the errors of the first refraction, yet it seemed not impossible for contrary refractions so to correct each other's inequalities as to make their difference regular; and if that could be conveniently effected, there would be no farther difficulty. Now to this end I examined what may be done, not only by glasses alone, but more especially by a complication of diverse successive mediums; as by two or more glasses or crystals, with water or some other fluid between them; all which, together, may perform the office of one glass, especially of the object glass, on whose construction the perfection of the instrument chiefly depends. But what the results in theory or by trials have been, I may possibly find a more proper occasion to declare."

Although the name of Dr. Halley is not associated with any brilliant effort in science, yet he was one of those few men who may be said to have improved and enriched almost every branch of natural knowledge. His labours in optics are perhaps less prominent than in other departments, though they are still entitled to notice in a history of its progress. In the Philosophical Transactions for 1693, he published a very valuable and popular paper on the "Excellence of the Modern Algebra in the resolution of the problem of finding the foci of optic glasses universally," in which he gives formulæ of a very simple kind, for finding the focus of rays passing near the axis, for lenses of all forms, and taking into account the thickness of the lens itself. In a paper on the rainbow, which appeared in the Transactions for 1700, Dr. Halley has computed the diameters, not only of the two bows, but of those which may be formed by a greater number than two reflexions. He finds that the first bow has a radius of 42° 30′, and the second 51° 55′, being both projected on the part of the sky opposite to the sun; that the third bow would be distant from the sun 40° 20′, (42° according to Dr. Young.) and the fourth 45° 33′. These two last bows, however, have never been observed, owing probably to the overpowering effect of the sun's light; though it is very probable that, under favourable circumstances, and with particular precautions, the third bow might be rendered visible. At all events, there is reason to believe that they will be visible to the inhabitants of Venus and Mercury.

The period to which we have now arrived embraces two capital discoveries, of which England has the sole and the undivided honour. These discoveries were the aberration of light, and the invention of the achromatic telescope. The history of the first of these discoveries, made by Dr. Bradly, has already been detailed at length in our article ABERRATION; and that of the second in the article on ACHROMATIC TELESCOPES.

There is perhaps no feature in the history of science more remarkable than the circumstance, that foreigners should have attempted to deprive England of the honour of the invention of the achromatic telescope, by endeavouring to transfer it to the illustrious Euler. There never was a scientific claim more utterly unfounded. From its first construction to its last improvements, the achromatic telescope is a British invention, to which no foreigner has made even the slightest addition; and, on the contrary, it may be stated with equal truth, that, excepting the recent and able investigations of Mr. Herschel, the mathematical theory of achromatic combinations belongs wholly to foreigners. The names of Euler, Clairaut, D'Alembert, and Boscovich, adorn these profound and ingenious inquiries; but while we admire the genius and address which they display, we must at the same time state with confidence, that they have never yet conducted to any practical or useful result.

We should have entered with zeal and pleasure into the discussion of the claims of Dollond, Klingenstierna, and Euler, and endeavoured to assign to the two last of these philosophers their real share in those preliminary inquiries, which terminated in the construction of an achromatic telescope by Dollond, in 1757; but such a discussion is now of no avail, as it is a matter of perfect notoriety, that this instrument was not only invented, but actually constructed in the year 1733, as mentioned in our account of the achromatic telescope. In that article we stated, "that if the claims of Mr. Hall are substantiated by unexceptionable evidence, we cannot withhold from him the evidence of being the original inventor.*" This evidence we believe to be complete. Mr.

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[*] As this part of the history of the achromatic telescope is very imperfectly known, our readers will be gratified with the following account of Mr. Hall's invention, from the *Gentleman's Magazine* for October, 1790. Dr Tilloch, who reprinted it in his Magazine for Nov. 1798, vol. ii. p. 177. has stated that he was assured by Mr Ramsden, that this paper contains a true statement of the facts.

"The inventor of the achromatic telescope was Chester More Hall, Esq. of More Hall in Essex, who, about 1729, as appears by his papers, considering the different humours of the eye, imagined they were placed so as to correct the different refrangibility

Dollond's patent was assailed before a British jury, on the ground of his having been anticipated by Mr. Hall, and before that stern tribunal it was proved that two of Mr. Hall's telescopes, consisting of lenses of crown and flint glass, and perfectly achromatic, were in existence long before Mr. Dollond had constructed the achromatic telescope; but, on the principle well known and long recognised in the patent law of England, that Mr. Hall's telescopes were not sold or exhibited for sale, the previous invention of the achromatic telescope was not held to invalidate the patent of Mr. Dollond, who had the merit of bringing it before the public as a useful invention. But although Mr. Hall must ever be regarded as the original inventor of the achromatic telescope, there is no reason, so far as we have learned, for supposing that Mr. Dollond had any knowledge of his instruments. The progress of Mr. Dollond's mind, indeed, from his first inquiries to the final completion of the telescope, render such a supposition highly improbable.

Mr. Peter Dollond, the son, had the merit of first suggesting and using the triple object glass, in which the lens of flint glass was placed between the two lenses of crown glass, for the purpose of obtaining a better correction of the spherical aberration. This arrangement has been long admired; but the double object glass will, we have no doubt, for many reasons, supplant this more complicated combination.

Although Euler had long refused to believe in achromatic refraction, yet his unbelief was founded chiefly on too obstinate an adherence to his own theoretical views. He was perplexed, however, with the distinct testimony of M. Clairaut, in favour of the excellence of the new telescopes; but he still ascribed their superiority to a variety of trivial causes. At one time he imputed it to the absorption of the red light by the green glass; at another time to the excellent curvature which he had given to the surfaces; and, at another, to the superiority of his eye-pieces. "If my theory, says Euler, be true, this disagreeable consequence follows, that Mr. Dollond's object glasses cannot be exempt from the dispersion of colours. Yet a regard to so respectable a testimony embarrasses me extremely, it being, as it is, as difficult to call in question such direct authority, as to abandon a theory which seems to me perfectly well founded, and to embrace an opinion which is as contrary to all the established laws of nature, as it is "*bizarre* and *revolting*." After all this, he still expresses his confidence that, in a darkened room, the object glasses of Dollond will be found to have the same defects as those of the common kind.

The force of truth, however, at last prevailed over Euler's attachment to theory; and he candidly acknowledges, that he should perhaps never have been brought to this conviction, had he not been assured by Clairaut, that the experiment of the English optician might be implicitly credited. This conviction was at last completed by a communication from M. Zeiher of St. Peterburgh, who found that by increasing the quantity of lead he could produce a glass, in which the dispersive power was much more increased than the refractive power. The following were Zeiher's results.

Proportion of Minium to Flint Glass.	Mean Refractive Power.	Dispersion; that of Crown Glass being 1000.
3 : 1	2.028	4800
2 : 1	1.830	3550
1 : 1	1.787	3259
$\frac{3}{4}$: 1	1.732	2207
$\frac{1}{2}$: 1	1.724	1800
$\frac{1}{4}$: 1	1.664	1354

Upon the new principles which were thus forced upon Euler's notice, he began the investigation of achromatic combinations, and wrote some able papers on the subject, which were published in the Memoirs of the Academy of Berlin. These, and some of his other optical writings, he collected into a work, under the title of *Dioptrica*, in three quarto volumes, which appeared at St. Petersburgh in the years, 1769, 1770, and 1771. The first volume is entitled *De Explicatione Principiorum ex quibus Constructio Telescopiorum quam Microscopiorum est petenda;* the second, *De Constructione Telescopiorum, Dioptricorum Appendice, de Constructione Telescopiorum Catoptrico-dioptricorum;* and the third, *De Constructione Microscopiorum tam Simplicium quam Compositorum.*

Among the optical of labours Euler, we must not omit to mention his attempt to establish a new theory of light. This theory was fundamentally the same as that of Huygens, with the additional hypothesis, that the difference of colours depends on the different frequency of the vibrations or undulations which constitute light. This theory has been stated by its author in a very clear and popular manner, in his letters to a German princess; but it has not met with any support from succeeding philosophers. Dr. Thomas Young is of opinion, that Euler has injured the theory of Huygens, by injudicious additions to it, and has remarked that, if Euler's theory of the reflexion and pro-

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of light. He then conceived, that if he could find substances having such properties as he supposed these humours might possess, he should be enabled to construct an object glass that would show objects colourless. After many experiments, he had the good fortune to find these properties in two different sorts of glass; and by forming lenses made with such glass, and making them disperse the rays of light in contrary directions, he succeeded. About 1733 he completed several achromatic object glasses, (though he did not give them that name,) which bore an aperture of more than 2½ inches, though the focal length did not exceed 20 inches; one of which is now in the possession of the Rev. Mr. Smith of Charlotte Street, Rathbone Place. This glass has been examined by several gentlemen of eminence and scientific abilities, and found to possess the properties of the present achromatic glasses.

Mr. Hall used to employ working opticians to grind his lenses; at the same time he furnished them with the radii of the surfaces, not only to correct the different refrangibility of rays, but also the aberration arising from the spherical figure of the lenses. Old Mr. Bass, who at that time lived in Bridewell precinct, was one of these working opticians, from whom Mr. Hall's invention seems to have been obtained. In the trial at Westminster Hall, about the patent for making achromatic telescopes, Mr. Hall was allowed to be the inventor; but Lord Mansfield observed, that 'it was not the person who locked up his invention in his scrutoire, that ought to profit by a patent for such inventions, but he who brought it forth for the benefit of the public.' This perhaps might be said, with some degree of justice, as Mr. Hall was a gentleman of property, and did not look to any pecuniary advantage from his discovery; and, consequently, it is very probable that he might not have an intention to make it generally known at that time. That Mr. Ayscough, optician in Ludgate Hill, was in possession of one of Mr. Hall's achromatic telescopes, in 1754, is a fact, which at this time will not be disputed."

pagation of light were true, all bodies would have the properties of solar phosphori; and the refraction of the rarest of natural bodies would be incomparably greater than that of the densest is actually found to be.*

The theory of achromatic combinations was investigated with great ability by M. Clairaut, who published three ingenious dissertations on the subject, in the Memoirs of the Academy of Sciences for 1756, 1757, and 1761. In order to establish a complete theory of achromatic object glasses, Clairaut, with the assistance of M. Tournieres, made many experiments on the refractive and dispersive powers of different kinds of glass. In these experiments he employed a prism with a variable angle, which consisted of a plano-cylindrical lens, in which different parts of the cylindrical surface formed different angles with the plane side of the lens, and by observing the point on the cylindrical surface, where the ray was incident when the image was colourless, he could easily determine the angle which the tangent to this point formed with the plane face of the prism. Clairaut seems to have been the first person who noticed, that the proportionality of the dispersion of the two lenses was a condition essentially necessary to the perfection of the combination;† but he merely touched upon this important topic, and left the honour and the labour of pursuing it to his successors.

The celebrated d'Alembert succeeded Clairaut in the same inquiry. The third volume of his *Opuscules Mathematiques*, published in 1761, is entirely devoted to the subject of achromatic telescopes. He continued these investigations in the Memoirs of the Academy of Sciences for 1765; and in the 4th, 5th, and 7th volumes of his *Opuscules*, he has added several appendixes on the same subject. In these various papers, d'Alembert has examined the subject in every aspect, and has brought forward a variety of ingenious resources for correcting errors of figure and of refrangibility. He has proposed, in some cases, to place the lenses of the object glass at a small distance; to use eye-glasses of different refractive media; and to construct achromatic opera glasses with small magnifying powers, by means of a single object glass and a single eye-glass of different refractive and dispersive qualities. Although d'Alembert was so extremely sanguine respecting the value of the different methods which he proposes, as to express his conviction that achromatic telescopes would be improved by them to a degree scarcely credible; yet we regret to say that this conviction had no solid foundation. Many of his methods, though highly marked by the analytical skill of their author, are characterized by excessive and unnecessary refinement; and we have no hesitation in adopting the sentiment so well expressed by Mr. Herschel, "that from all the abstruse researches of Clairaut, Euler, d'Alembert, and other celebrated geometers, nothing hitherto has resulted beyond a mass of complicated formulæ, which, though confessedly exact in theory, have never yet been made the basis of construction for a single good instrument, and remain therefore totally inapplicable, or at least unapplied in practice."‡

Among the mathematical writers on the achromatic telescope, the name of the celebrated Boscovich holds a prominent place. His dissertations, which, though very diffuse, are written with much perspicuity, were first published at Vienna in 1759, under the title of *Dissertationes Dioptricæ*. He resumed the subject in the *Commentarii Bononienses*; but it is in his *Opera Pertinentia ad Opticam et Astronomiam*, which he published at Bassano in 1785, in five quarto volumes, that we are presented with his most recent and most correct investigations. The two first volumes are entirely occupied with optical subjects, and the first, and half of the second, are devoted to the subject of achromatic telescopes.

In examining the refractive and dispersive powers of bodies, Boscovich used a variable prism, which was an improvement upon Clairaut's, as suggested by Abat of Marseilles. It consisted of two plano-cylindrical lenses, one of which was plano-convex, and the other plano-concave, so that when the plano-convex and plano-concave surfaces were put together, the one could be moved upon the other, and any inclination, within certain limits, given to the plane surfaces. For the purpose of examining fluids, he employed an apparatus which he calls a *Vitrometer*, consisting of two glass planes which could be set at different angles, so as to form fluid prisms of any angle. Our author then proceeds to investigate formulæ for correcting the spherical and chromatic aberrations for double and triple achromatic object glasses. Having considered fully the irrationality of the coloured spaces first treated of by Clairaut, he shows that it is impossible to unite more than two colours by the opposite refraction of two substances, which have not their dispersions proportional; and he points out a method of uniting the two extreme rays of the spectrum with the most outstanding colour by means of a third medium. One of the most interesting of Boscovich's dissertations, is that which relates to the construction of achromatic eye-pieces. He has here treated the subject in a very general and interesting manner, and has pointed out a method of making achromatic eye-pieces, either with two lenses put together of different dispersive powers, like the object glass;—with two lenses of the same refractive and dispersive powers placed at a distance, equal to half the sum of their focal length;—or with three or four lenses of the same glass.

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* Quod si ob difficultates physicas in speculis idoneis torno elaborandis et poliendis, etiamnum lentibus uti oporteat, fortassis media diversæ densitatis ad lentem objectivam componendam adhibere utile foret, ut a natura factum observemus in oculi fabrica, ubi christallinus humor (fere ejusdem cum vitro virtutis ad radios lucis refringendos) aqueo et vitreo (aquæ quoad refractionem, haud absimilibus) conjungitur, ad imaginem quam distinctè fieri potuit, a natura nihil frustra molienti, in oculi fundo depingendam: sed et alii sunt in animalis oculo prædicti artificii usus, qui non sunt hujus loci."

In Dr. Brown's Translation of Gregory's Catoptrics, the words *fortassis media, &c.* are translated, "perhaps it would be of service to make the object lens of a different medium," which destroys entirely the meaning of the author, as he clearly recommends the trial of media of different density to compose the object glass.

† "Il y a encore," says Clairaut, "un fait important que nos experiences nous ont appris, c'est que les corrections des iris faites par les prismes combinés, ne sont jamais aussi parfaites qu'on le croiroit d'apres les termes de M. Dollond Dans le cas du prisme de verre placé dans l'eau; par exemple, apres avoir fait varier les plaques qui determinent l'angle du prisme d'eau, jusqu'au point ou les objects vûs à travers les deux prismes ne paroissent point décolorés, du moins aux vûes ordinaires, on trouve en placant ces prismes dans la chambre noire, qu'il reste toujours quelque petit limbe de couleur vers les bordes de l'image du soleil, ce qui vient sans doute de ce que les parties du spectre que chaque matiere réfringente donne, ne sont pas exactement proportionelles aux longueurs totales de ces spectres Mais ces inégalités qui diminuent à mesure que les angles des prismes, sont plus petits, doivent etre comme insensibles dans le cas des lentilles adossées, vû la petitesse des angles de refringence equi ont lieu alors.

‡ *Phil. Trans* 1821. p 222.

The subject of *Photometry*, or the mensuration of the intensity of different lights, had till now scarcely attracted the notice of philosophers. Huygens had thrown out some imperfect hints, and had pointed out a method of estimating the quantity of light which Jupiter and Saturn received from the sun, and of comparing the light of the sun with that of the fixed stars; and P F. Marie had published, in 1700, a work entitled, *Nouvelle decouverte sur la Lumiere, pour en mesurer et compter les degres*, in which he describes an instrument called a *Lucimeter*. It was reserved however for M. Bouguer to give a new character to these investigations, and to add many curious facts to the science of optics. His first experiments on the subject were published so early as 1729, in a work entitled, *Essai d'Optique sur la Gradation de la Lumiere*, which afterwards appeared in 1760, in an augmented and improved form, under the title of *Traité d'Optique sur la Gradation de la Lumiere*. This work contains numerous experiments on the properties of a variety of substances in the reflexion and transmission of light under different circumstances. It treats of the intensity of the light emitted by the sun, the moon, the planets, and the fixed stars; of the quantity of light reflected, at different angles, from polished and rough surfaces; and of the absorption or dispersion of light in passing through transparent media. In his observations on the light of the planets, he showed that the centre of the sun's disk was considerably more luminous than the extremities of it; that the primary and secondary planets are, on the contrary, more luminous at their edges than near their centres; and that the light of the sun is about 300,000 times greater than that of the stars. M. Bouguer likewise found, that when one light was 64 times less than another, the presence of the weaker one could not be perceived. He found that when the sun was 15° or 20° high, the light decreased on the same horizontal parallel to the distance of 110° or 120° from his body, and then increased again to the point exactly opposite to the sun; and from various observations on the light of the sun and moon, at different altitudes, he concludes that light is diminished in the ratio of about 2500 to 1681, in traversing 7469 toises of dense air. In his experiments on the reflexion of light from water, glass, and metallic surfaces, he obtained many new and curious results. At an incidence of 75°, or 15° with the plane, he found that a piece of glass one line in thickness, reflected 628 rays out of 1000; while a metallic mirror, placed under the same circumstances, reflected only 561. In like manner, water at a perpendicular incidence, reflected only 18 out of the 1000, or $\frac{1}{37}$th of the number reflected by mercury. At great angles of incidence the water reflected almost exactly as much light as the quicksilver. This interesting result may, to a certain degree, be observed, by pouring a little water upon mercury, and observing the two images that are reflected from the aqueous surface, and the other from the separating surface of the two fluids, viz. the surface of the mercury. At a perpendicular incidence, the image from the water will be scarcely visible. By increasing the incidence, the image from the water will grow stronger, while that from the mercury will become weaker in proportion, till at angles of about 80° and more the two images will be equally luminous. This comparison, however, is in a great degree fallacious, as a measure of the comparative reflexion, for the rays are not incident at equal angles upon both surfaces, and as the light which falls upon the mercury is much weaker than that which falls upon the water.

M. Bouguer was followed in this interesting inquiry by M. Lambert, an ingenious German philosopher, who published an account of his researches in his *Photometria, seu de Mensura et Gradibus Luminis, Colorum, et Umbræ*, which appeared at Augsburg in 1760. In this interesting work, our author determines by experiment the quantity of light reflected by the exterior and interior surfaces of glass at all angles of incidence, and he connects these experiments by general formulæ, which represent them with remarkable accuracy. He applies these experiments to several glasses, and he thus obtains for every angle of incidence results which Bouguer had sought only for perpendicular incidences. He treats of the diminution of light in passing through the atmosphere. He gives a theory of the intensity of direct light, and the brightness of illuminated objects compared with that of the light which illuminates them. He discusses the brightness of images in the focus of a burning glass, compared with that proceeding from the radiant object; and he introduces into the calculation the quantity of light which the surface of glass reflects, as well as coloured glasses and all other bodies, whether white or coloured. He calculates the illumination of the planetary system, the brightness of the earth, the planets, and the fixed stars and their phases, as seen from the earth, along with their illuminating power. In this inquiry the theory of Lambert corresponds perfectly with the experiments of Bouguer on the relative intensities of the solar and lunar rays. He inquires into the different degrees of shade, comprehending those of the twilight and of the evening. He describes instruments for determining the intensity of colours, and of their mixture. He calculates the brightness of objects in so far as it depends on the aperture of the pupil; and he determines in what manner the true lustre of objects differs from that which the eye attributes to them, in consequence of the refractions of the eye and the aperture of the pupil.

The limits of this article will not permit us to give an account of all the writers, who either wrote upon optics, or who endeavoured by their experiments to extend the boundaries of the science. Dr. Porterfield's investigations of the functions of the human eye added considerably to our knowledge of that organ; and the observations of Dr. Jurin on that and upon other subjects deserve very considerable praise. The experiments of the Abbé Mazeas on thin plates, and of M. Dutour and M. Comparetti on the inflexion of light, though evincing much ingenuity and industry, nevertheless contain no general result which could influence the progress of optics. The experiments of Buffon, Scheiffer, and Dr. Robert Darwin, on ocular spectra and accidental colours, throw much light on a subject which is still but little understood. Mr. Delaval made some ingenious experiments on colours, which seem to prove, that all the colouring matters in common use owe their tints to rays which are refracted from white light during its transmission through their substance. Mr. Thomas Melville, a Scottish writer of great promise, but who was cut off, in 1753, at the early age of 27, made a number of interesting experiments on vision, and other optical subjects, which are recorded in a posthumous paper published in the 2d volume of the *Edinburgh Philosophical* *and Literary Essays;* and Mr. Mitchell has published, in Priestley's Essay on Vision, many acute odservations and curious facts on the various branches of light and colours. The science of optics received essential service from the *Compleat System of Optics*, which was published by Dr. Robert Smith of Cambridge, in the year 1738. It consisted of four books, viz. a popular, a mathematical, a mechanical, and a philosophical treatise, with a very interesting appendix on distinct and indistinct vision, by Dr. Jurin, to which we have already alluded. The work of Dr. Priestley, entitled "*The History and present State of Discoveries relating to Light and Colours*," which appeared in 1772, is peculiarly fitted for disseminating optical knowledge among general readers, and was the means of making the philosophers of this country better acquainted with the labours of continental authors.

Although many profound researches and ingenious experiments and inquiries relative to detached branches of the doctrine of light have marked the interval of nearly a century, which elapsed from the time of Newton's discoveries to the period at which we are now arrived, yet the only great discovery which can be said to characterize it, is that of the achromatic telescope. The science of optics, however, was destined to receive still grander accessions; and there is no period of its history in which the science of light has been enriched with such splendid and unlooked for discoveries, as that period which begins with the labours of Dr. Herschel, and ends with those of his son.

When Dr. Herschel began to devote himself to the sciences, the number and condition of the planetary bodies seem to have been considered by astronomers as permanently established. A whole century had elapsed since Cassini discovered the belts and satellites of Saturn, and after that period no addition of the least importance had been made to the natural history of the heavens. When Dr. Herschel had settled in England, he amused himself with the construction of reflecting telescopes, and, after considerable experience, he was enabled not only to form excellent compositions for his specula, but also to give them a true parabolic figure and an exquisite polish. Having early observed that nothing was to be done with very small telescopes, he executed several *seven* feet in focal length, and others of *ten*, *fifteen*, and *twenty* feet. "When I resided at Bath," says Dr. Herschel, "I had long been acquainted with the theory of optics and mechanics, and wanted only that experience which is so necessary in the practical part of these sciences. This I acquired by degrees at that place, where in my leisure hours, by way of amusement, I made for myself several 2 feet, 5-feet, 7-feet, 10-feet, and 20-feet Newtonian telescopes; besides others of the Gregorian form, of 8 inches, 12 inches, 18 inches, 2 feet, 3 feet, 5 feet, and 10 feet focal length. My way of doing these instruments at that time, when the direct method of giving the figure of any of the conic sections to specula was still unknown to me, was to have many mirrors of each sort cast, and to finish them all as well as I could, then to select by trial the best of them, which I preserved; the rest were put by to be re-polished. In this manner I made not less than 200 7-feet, 150 10-feet, and about 80 20-feet; not to mention those of the Gregorian form, or of the construction of Dr. Smith's reflecting microscope, of which I also made a great number."* Through these instruments he surveyed the heavens with unwearied assiduity, and with proportional success. The discovery of a new planet attended with six satellites; of two new satellites belonging to Saturn; the double ring and quintuple belt of the same planet; of various new phenomena relative to the rotation, figure, and general appearance of the old planets; of volcanoes in the moon, and of the changes which are going on in the disk of the sun, were the results of his indefatigable labours. The construction of the milky way yielded to Dr. Herschel's telescopes; and the whole subject of nebulæ, double and triple stars, may be considered as entirely his own. Not content with the fine instruments which conducted him to these splendid discoveries, Dr. Herschel conceived the idea of constructing them of a still larger size. He had begun in the year 1781 to make a 30 feet aerial reflector, with a mirror 36 inches in diameter; but the metal having cracked at one time in the cooling, and at another time run into the fire in consequence of the furnace giving way, a temporary stop was put to his design. In 1783, he had finished a very good 20 feet reflector, with a large aperture; and after two years' observation with it, he was so much convinced of the advantages of such apertures, that he resumed his intention of increasing them still farther. Sir Joseph Banks, that indefatigable patron of science, submitted Mr. Herschel's design to our late gracious sovereign George III. who immediately offered the means of accomplishing so desirable an object. In consequence of this act of liberality, so honourable both to the giver and the receiver of it, Mr. Herschel began to construct a telescope *forty* feet in focal length, about the end of the year 1785. The diameter of the great speculum was 48 inches of polished surface, its thickness about 3½ inches, and its weight 2118 pounds. With proper eye-glasses it magnifies about 6000 times. The method of observing is by what is called the *Front View*, the observer being suspended in a seat at the mouth of the tube, with his back to the object, and viewing the reflected image either with his naked eye, or with an eye-glass attached to the side of the tube. This noble instrument was completed on the 27th August, 1789; and on the following day, having brought the telescope to the parallel of Saturn, Dr. Herschel had the good fortune to discover a sixth satellite to that planet.

While Dr. Herschel was examining the phenomena upon the disc of the sun, he had occasion to employ various coloured glasses for obstructing the light of that luminary. In using some of these he experienced a sensation of heat when there was very little light, and *vice versa*, and was thus led to conjecture that the rays of the spectrum had different powers of heating, as well as of illuminating objects. He immediately projected a series of experiments on the subject, which were conducted with much sagacity and care; and in measuring the heating power of the red rays, he was surprised to find that the thermometer still rose when it was placed a little without the red extremity of the spectrum. In this way he was conducted to that curious and important discovery of invisible rays beyond the red, which had the power of heating, but not of illuminating, objects. Dr. Herschel was anxious to determine the refrangibility of the extreme rays that possessed the power of heating; but he found this a very difficult task, and was able only to ascertain, that at a distance of 52 inches from the prism, the invisible rays still exerted a considerable heating power even at a point $1\frac{1}{2}$ inches distant from the extreme red ray.

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* *Phil. Trans.* 1795, vol. lxxxv. p. 347.

In the year 1809. Dr. Herschel communicated to the Royal Society, a series of curious observations on thin plates; but in this inquiry his experiments were attended with less success.

About the year 1787, our ingenious countryman, Dr. Robert Blair, conceived the idea of availing himself of different fluid media in the construction of the achromatic telescope; and, in the beginning of 1791, he communicated an account of his experiments to the Royal Society of Edinburgh, in a paper entitled "*Experiments and Observations on the Inequal Refrangibility of Light*," and published in the *Edinburgh Transactions*, vol. iii. p. 1. By the application of a number of glass prisms of different angles,* to a standard prism containing a portion of the fluid to be examined, he determined the relative dispersing qualities of various fluids. He has shewn that the quality of dispersing light in a greater degree than crown glass is possessed by the solutions of metals, the essential oils, and all the mineral acids except the sulphuric; but after constructing many object glasses on the common achromatic principle, in which the correction of colour was affected either by two fluid lenses, or a lens of crown glass united with one of fluid, he found that the correction of colour was never complete, in consequence of the green rays being among the most refrangible rays in crown glass, while they were among the least refrangible in all the refracting media that he had hitherto examined. The result of this was, that when the combination was executed in the most perfect manner, a secondary spectrum, consisting of a green and a wine coloured fringe, remained uncorrected. This remarkable fact, which, as we have already seen, was known both to Clairaut and Boscovich, would have damped any expectations that had been entertained of removing completely the aberration of colour, had not Dr. Blair been so fortunate as to discover that a fluid in which the particles of muriatic acid and metallic particles hold a due proportion, had a greater dispersive power than crown glass, and at the same time refracted all the orders of rays exactly in the same proportion as the glass does, and hence he concluded that rays of all colours which diverge by the refraction of the glass, may either be rendered parallel by a subsequent refraction made in the confine of the glass and this fluid; or by weakening the refractive density of the fluid, the refraction which takes place in the confines of it and glass may be rendered as regular as reflexions, while the errors arising from unavoidable imperfections of workmanship, are far less hurtful than in reflexion, and the quantity of light transmitted by equal apertures of the telescope much greater. This curious property in the muriatic acid led Dr. Blair to complete success in constructing telescopes, in which the aberration of colour was completely corrected. The doctor took out a patent for this very valuable improvement in achromatic telescopes; but practical difficulties were experienced in the manufacture of them for sale, which prevented the patentee from deriving any pecuniary advantage from his indefatigable and successful labours. Even when the fluids were confined in the most perfect manner, a chemical change, and sometimes even crystallization, was found to take place, which completely destroyed the perfection of the instrument. The only philosopher that we know of, who actually looked through the telescopes of Dr. Blair, was Dr. Robison, who always spoke of them in terms of the highest praise. He informs us indeed, that Dr. Blair had a telescope not exceeding *fifteen* inches in length, with a compound object glass, which equalled in all respects, if it did not surpass, the best of Dollond's, forty-two inches long The effect of this telescope, when applied to the examination of double stars, was, we understand, particularly fine; and it is deeply to be regretted that Dr. Blair was not encouraged by some public aid to carry on the manufacture of such valuable instruments. For ordinary purposes telescopes of this kind may be considered as too delicate and complex; but admitting in its full force the objection to them, drawn from the change which either does or may take place in the fluid media, their use in public observatories, and particularly their application to fine graduated instruments, were objects of primary importance to the progress of astronomy, even if the lens required to be renewed every two or three years.

The science of optics, as well as many other branches of physics, received very important accessions from the labours of our countryman, Dr. Thomas Young. In the year 1793, Dr. Young communicated a paper to the Royal Society of London, entitled "Observations on Vision," in which he endeavours to show that the fibres of the crystalline lens are muscular, and are inserted in the radial tendons or septa, observed by Leuenhoek in the lenses of several animals, and that the accommodation of the eye to different distances is effected by the change of form which the action of these fibres produces in the lens. Notwithstanding the almost universal prevalence in England of the Newtonian doctrine, that light was emitted from the sun and other luminous bodies in the form of material particles, yet Dr. Young boldly contradicted this opinion in a very elaborate paper, entitled, "Outlines of Experiments and Observations respecting Sound and Light," which was read before the Royal Society in the beginning of the year 1800. In this able paper Dr. Young revives the opinions of Hook, Huygens, and Euler, that light has a strong analogy with sound, and consists in the undulations of an ethereal medium, pervading all matter. In the same year Dr. Young communicated to the Society another paper "on the Mechanism of the Eye," containing a great number of very acute and valuable observations on the structure and functions of that interesting organ. In this paper Dr. Young describes a new *Optometer*, for ascertaining by inspection the exact focal length of any eye, and the remedy for any degree of short-sighted or long-sighted vision. By the immersion of the cornea of his own eye in water, he shows that its power of accommodating itself to different distances, cannot arise from any change in the curvature of that tunic; and in like manner, by confining it at the extremity of its axis, he demonstrates that no material alteration of its length could take place. He then examines what inference can be drawn from the experiments hitherto made on persons deprived of the lens, and he finally deduces from the aberration of the lateral rays, an argument in favour of a change in the figure of the crystalline; and ascertains, from the quantity of this aberration, the form into which the lens appears to be thrown in his own eye, and the mode by which he conceives the change must be produced in that of every other person. In this paper Dr. Young likewise endeavours to ascertain the exact arrangement of the fibres in the human crystalline, which seems to have baffled the attempts of Leuenhoek and other observers, and he states that the number of radiations are ten on each side. This result, however, is incorrect, as will be seen in a future part of this historical sketch.

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* In giving an account of the experiments of Dr. Blair, Mr. Leslie remarks, "that this way of experimenting was sufficiently simple; but a *more accurate and expeditious method might easily have been devised.* For instance, if the prism, furnished with a graduated arch, had remained fixed, and a single glass wedge made to turn upon it, and present successive inclinations to the observer, the refracting angle at which the irregular colours were united, could be deduced by an easy calculation." This contrivance obviously appears to be given as a device of the learned professor's; but he should have known, as he possessed a copy of the work, that this very contrivance is fully described and represented by a drawing in Dr. Brewster's *Treatise on New Philosophical Instruments*, published in Edinburgh in March 1813, and is the one which he used in the determination of the dispersive powers of the great variety of substances which he subjected to examination.

In another paper on "The Theory of Light and Colours," published in 1808, Dr. Young resumes the consideration of the undulating system, and applies it to the explanation of every natural phenomenon. He supposes that a luminiferous æther pervades the universe, rare and elastic in a high degree; that the number of different colours depends on the different frequency of vibrations excited by light on the retina; and that all material bodies are to be considered with respect to the phenomena of light, as consisting of particles so remote from each other as to allow the ethereal medium to pervade them with perfect freedom, and either to retain it in a state of greater density and of equal elasticity, or to constitute, together with the medium, an aggregate which may be considered as denser, but not more elastic. He then proceeds to demonstrate some of the leading phenomena of undulation in an elastic medium, and he considers the colours of striated surfaces, of thin and of thick plates, and those produced by inflexion, as the joint effect of two undulations from different origins, coinciding either perfectly or very nearly in direction. In the following year Dr. Young published "An Account of some cases of the production of colours not hitherto observed." The new colours which Dr. Young describes in his paper are those of delicate fibres, and of mixed plates. The former he ascribes to the interference of two portions of light, one reflected from the fibre, and the other bending round its opposite side, and at last coinciding nearly in direction with the former portion. The colours of mixed plates are those which are produced by light passing through two pieces of plate glass, having between them either moisture, butter, or tallow. A candle seen through the plates had a sort of halo round it, and Dr. Young observed that the moisture was intermixed with portions of air, whenever the coloured fringes were visible. These colours were always exhibited when the interstice between two glasses, nearly in contact, was filled with a great number of minute portions of two different substances, mixed, such as water and air, oil and air, or oil and water. Dr. Young considered them as produced by the light which passes through one of the mediums moving with greater velocity, and anticipating the light passing through the other.

This curious paper was followed in 1803 with another, entitled "Experiments and Calculations relative to Physical Optics." In these papers, Dr. Young has given an experimental demonstration of his general law of interference, by showing that fringes of colours are actually produced by the interference of two portions of light. We have already seen, in our account of the labours of Grimaldi and Newton, that the shadows of bodies placed in divergent light are divided by parallel fringes, similar to those on the outside of the shadow. By intercepting the light which fell on one side of the inflecting body, Dr. Young found that these parallel fringes disappeared, and this took place whether the interception was effected on one side or the other. Hence it followed that the parallel fringes were produced by the interference of portions of light that passed by both the edges of the inflecting body. The colours of the supernumerary rainbow, or those repetitions of coloured arches which appear within the common bow, are referred by Dr. Young to the same law of interference.

In his work on *Medical Literature*, published in 1813, Dr. Young has given the description of an ingenious optical instrument, which he calls an *Eriometer*, for measuring the diameter of particles held in suspension, and also of all kinds of fibres, and the diameter of the coloured rings which they produce; the diameter of the first ring, for example, always increasing as the diameter of the particle or the fibre diminishes. With this instrument he has determined the diameter of various bodies, from the seed of the *lycoperdon bovista*, to that of the coarsest wool, the first being $3\frac{1}{2}$, and the last 60, in his eriometrical scale. In the same work Dr. Young has described some curious phenomena of changeable colours, which he explains in a very satisfactory manner by the general law of interference, and to the same principle he refers the glories, or the white and coloured circles which often appear when clouds are passing over the sun and moon.

In concluding this notice of Dr. Young's optical labours, it is satisfactory to state, that the general law of interference which he has discovered, has found an extensive application in a variety of phenomena discovered since the time of its publication; that he most happily applied it to explain the colours of crystallized plates; that the law itself has been confirmed by succeeding discoveries; and that its author is likely to enjoy the honour of having established, on the basis of direct experiment, a theory of light and colours, which had formerly no other support but that of vague reasoning, and unsatisfactory analogies.

The discovery of invisible rays of heat had directed the attention of philosophers to the phenomena of the spectrum. M. Ritter, of Jena, had conceived that the rays might have different chemical properties; and repeating the experiments of Herschel, on the 22d February 1801, he exposed muriate of silver to different parts of the spectrum, and found his conjecture completely verified. The muriate very soon became black beyond the violet edge of the spectrum, blackened a little less in the violet itself, the action becoming less in the blue, and diminishing more and more till it vanished. When muriate of silver, a little blackened or disoxygenated, was used, its whole colour was partly restored by the red, and still more by the invisible rays beyond it. From these experiments M. Ritter concluded that the solar spectrum is accompanied with two sets of invisible rays; one on the red side, which favours oxygenation, and the other on the violet side, which favours disoxygenation. M. Ritter found that phosphorus emitted white fumes in the invisible red, but in the invisible violet phosphorus in a state of oxygenation was instantly extinguished. This ingenious philosopher is also said to have discovered, that when the eye is kept for some minutes in contact with the negative conductor of Volta's pile, all objects will appear red, and after it is kept in contact with the positive conductor, all objects will appear blue.

In reviving the science of optics, and extending its boundaries, the labours of Dr. Wollaston were highly conspicuous. The subject of double and inverted images, caused by atmospheric refraction, had about this time attracted the notice of natural philosophers. Mr. Huddart seems to have first observed a distinct inverted image beneath the object itself, and, in the *Philosophical Transactions* for 1797, he has described several similar appearances, and has shown that the lowest strata of air were at the time of their production endowed with weaker refractive power than others at a small elevation. In the same work for 1797, Mr. Vince has described a case where erect as well as inverted images were visible above instead of beneath the objects, and he refers these phenomena to unusual variations of increasing density in the lower strata of the atmosphere. In this state of the subject Dr. Wollaston began his inquiries, and communicated the result of them to the Royal Society in the year 1800, in a paper entitled, "On Double Images caused by atmospherical refraction." In the theory by which he explains the phenomena of this kind of refraction, it is supposed that there are two opposite states of the atmosphere, either of which may occasion objects to be seen doubled or tripled, since both increase and decrease of its density, when partial, produce similar effects. He explains why air heated by the moderate warmth of the sun's rays occasions objects to appear double and inverted; —why rarefaction by a higher degree of heat gives an additional image, which is not inverted;—in what state of evaporation the increase of the air's density brings distant objects into view by unusual elevation; and under what circumstances evaporation may also produce an inverted image less elevated.

In the year 1802, Dr. Wollaston published in the Philosophical Transactions, "A Method of Examining Refractive and Dispersive Powers by prismatic reflexions." By means of a square glass prism, and a simple apparatus attached to it, Dr. Wollaston observes the angle at which the visual ray began to be totally reflected, and at which the object ceases to be seen by refraction. In flint glass in contact with air, the angle is about 39° 10′; but when the object is connected with the glass by water, oil, or any cement, the angle increases according to the refractive power of the water, oil, or cement. With this instrument, which possesses many advantages, but is not entirely free from defects, Dr. Wollaston drew up a table of refractive powers, containing 82 bodies, of the greater part of which he found the index of refraction. In this table, *Air* and *Water* stand at the bottom of the table, and *Diamond* at the top. Dr. Wollaston then applies the same principle to the measurement of dispersive powers. He points out a number of cases, in which the order of colours is reversed by the disparity in the dispersive powers of two media, and he gives a table of the order of dispersive powers of 33 bodies, beginning with *Sulphur*, and ending with *Fluor Spar*.

The most important part of the preceding paper, is that which relates to the colours of the spectrum. "I cannot," says he, "conclude these observations on dispersion without remarking, that the colours into which a beam of white light is separable, appear to me to be neither *Seven*, as they are usually seen in the rainbow, nor reducible, by any means that I can find, to *Three*, as some persons have conceived; but that by employing a very narrow pencil of light, *Four* primary divisions of the prismatic spectrum may be seen with a degree of distinctness that has not been described, nor observed before." The *Four* colours which Dr. Wollaston thus observed, were *Red*, *yellowish Green*, *Blue*, and *Violet*, which, with all the substances that disperse either very much or very little, he found to occupy the following spaces, the whole length of the spectrum being 100, and the incident light making equal angles with two of the sides of the prism.

Red	16	Blue	36
Yellowish Green	23	Violet	25
	—		—
	39		61

When the inclination of any prism, however, was altered so as to increase the dispersion of the colours, the proportions of them to each other were also changed, so that the red and green spaces together, in place of being 39, were sometimes 42, and the blue and violet, in place of being 61, were sometimes 58. In our observations on Newton's discoveries,* we have already remarked the singularity of the circumstance, that this mode of analyzing a beam of light should have been so long unnoticed; and though Dr. Wollaston's paper has been published nearly 20 years, this very important part of it is in a great measure unknown even in England.

About this time, as we have already seen, M. Ritter had discovered the chemical or deoxydating invisible rays beyond the violet extremity of the spectrum. Dr. Wollaston, without knowing of what had been done by Ritter, made the same discovery. Scheele had long ago mentioned, that muriate of silver, when exposed to the prismatic spectrum, was more blackened in the violet *rays* than in any other kind of light. In repeating this experiment, Dr. Wollaston found that the darkness extended not only through the space occupied by the violet, but to an equal degree, and about an equal distance beyond the visible spectrum, and that by narrowing the pencil of light received in the prism, the discoloration may be made to fall almost entirely beyond the violet.

In the continuation of these experiments, Dr. Wollaston discovered new chemical effects of light, of which he published an account in 1804.† Having found that gum *Guiacum* acquired a green colour when exposed to light and air at the same time, he took two portions, and exposed one to light and the other to air alone. In five minutes the first had acquired a perceptible green colour, and in a few hours it had got all the colour it seemed capable of receiving; while the colour of the other was not changed after many months.

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* See page 607.

† See Nicholson's *Journal*, Aug. 1804, vol. viii. 8vo. p. 293.

He then dissolved some guiacum in alcohol, and after having washed a card with the tincture, he exposed it for some time to different parts of the prismatic spectrum, but observed no change of colour. He therefore took a lens, seven inches in diameter, and having covered up its surface, excepting a ring of one-tenth of an inch at the margin, he could produce a focus of any colour, the focal distance for yellow rays being about 24½ inches. With this apparatus, muriate of silver was blackened much more quickly than in the ordinary spectrum; and when the paper, tinged with the solution of guiacum, was cut into small pieces, it acquired a green colour in the focus of the most refrangible rays. In the focus of the most luminous rays, no effect was produced. Pieces of the guiacum paper already made green, were now placed in the focus of the least refrangible rays, and the green colour was completely removed, and the guiacum restored to its primitive yellow hue. In carbonic acid gas the guiacum could not be rendered green at any distance from the lens, but was speedily restored from green to yellow, by exposure to the red rays. Dr Wollaston also found that the posterior surface of a heated silver spoon removed the green colour from the guiacum paper as completely as when it was in the focus of solar heat.

In examining the refractive power of Iceland spar, Dr. Wollaston perceived that the law of the extraordinary refraction in that substance, as given by Huygens, might be verified with great facility by means of his instrument already described. He accordingly measured the extraordinary refraction in different planes, and found the results to agree in a most remarkable manner with the Huygenian law.

In an account of the labours of this eminent philosopher, we must not omit to notice the periscopic principle, by which he improved the camera obscura and the glasses for spectacles. In place of making the lenses doubly convex and doubly concave, he has shown that a much greater range of distinct vision may be obtained, by making every lens concave towards the eye and convex towards the object, whether it is intended for persons that are long or short-sighted.

The papers of Dr. Young on the Huygenian theory, and Dr. Wollaston's determination of the double refraction of Iceland spar, by means of his new instrument, seem to have drawn the attention of the philosophers of Europe to the subject of double refraction. M. Laplace had attempted to refer the deviation of the extraordinary ray to the action of those attractive and repulsive forces, by which the ordinary refraction and reflexion of light are produced; and with the view of obtaining some additional knowledge of this intricate subject, the Institute of France, in 1808, proposed the double refraction of light, as the subject of a prize to be adjudged in 1810. Two or three memoirs were written for this prize; but only one of these satisfied the expectations of the Institute.

The successful memoir, which was crowned by the Institute in 1810, was the production of E. L. Malus, Member of the Institute of Egypt, and Colonel of the Imperial Corps of Engineers. Exhausted with the fatigues of the fatal expedition to Egypt, and with the diseases of that insalubrious climate, Malus returned to France, to pursue in quiet the peaceful researches of science. Not long after his return, he had made himself known to the Institute, by his *Traité de Optique*, a work, in which he treated in the most general and rigorous manner all the phenomena of reflexion and refraction that depend on geometry alone. No sooner was the prize of double refraction announced, than Malus entered with zeal on the study of that difficult subject. He measured with great accuracy all the phenomena of double refraction with natural and artificial faces, and in planes differently inclined to the axis of the rhomb; and on examining afterwards, by means of these observations, the different laws which philosophers had proposed for explaining the phenomena, he was struck with their admirable coincidence with the theory of Huygens, and was soon convinced that this law was in reality that of nature. In developing the analytical formulæ for comparing the law with experiment, he found that it not only satisfied all the phenomena which Huygens himself had observed, but also those which had escaped his notice. While engaged in the experimental part of his inquiry, he resided in the Rue des Enfers, in Paris, and happening to turn a doubly refracting prism to the windows of the palace of the Luxembourg, which were then illuminated by the setting sun, he was astonished to observe that one of the images of the windows vanished alternately during the rotation of the prism; and in speculating upon this unexpected phenomenon, he at first attributed it to some change of character which the light had received during its oblique transit through the atmosphere. Unable to explain the phenomenon upon this supposition, he was led to try whether or not the glass was the cause of it, and he found to his inexpressible delight that the beam of the setting sun, which had been reflected from the windows of the Luxembourg palace, had acquired the property which he observed, by being reflected from the panes of glass. In pursuing this experiment through its various modifications, Malus was conducted to his great discovery, which may be considered as forming an epoch in optical science, *that when a pencil of light is reflected by the surface of water at an angle of 52° 45′ with the vertical, the reflected light has all the character of one of the pencils produced by the double refraction of a crystal*, the plane of reflexion, in general, replacing the plane of the principal section of the first crystal. This reflected ray has all the characters of an *ordinary* ray produced by the refraction of a crystal, whose principal section is parallel to the plane of reflexion, or of an extraordinary ray formed by a crystal, whose principal section is perpendicular to the same plane. When the pencil reflected from the surface of water was made to fall upon another transparent surface,* at nearly the same angle, of 52° 45′, but so that the plane of this second reflexion is parallel with the first plane of reflexion, the light thus incident will be partially reflected, as in all common cases; but if the plane of reflexion from the second surface is at right angles to the first plane of reflexion, then the incident light will be entirely refracted, and not a single ray of it will suffer reflexion.

These two remarkable properties are produced by reflexion from all transparent solids or fluids, with this difference only, that the angle at which this modification is impressed upon the light is invariable, being in general greater for bodies that have a greater refractive power. On each side of this angle, which has been called the maximum polarising angle, a part of the rays are, according to Malus, more or less modified, and in a manner analogous to what takes place between two crystals, whose principal sections are neither parallel nor rectangular.

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* This surface should also have been water, but, as the surface of water cannot be placed in any other position than a horizontal one, Malus made the ordinary and extraordinary pencils, formed by Iceland spar, fall upon the water at an angle of 52° 45′. The same experiment he afterwards made with two plates of glass, upon which he caused the rays to fall at an angle of 54° 35′.

When the light is incident on a thick plate of any transparent solid or fluid, Malus found that this pencil, reflected from its posterior surface, had acquired the same character with the pencil reflected from the first surface, and therefore he concluded that the sine of the maximum polarising angle at the first surface was to the sine of that at the second surface, as the sine of incidence was to that of refraction.

These curious discoveries were soon followed by others of not inferior importance. On the 11th March, 1811, M. Malus announced to the Institute, that in examining the light transmitted, when the ray was polarised by reflection, he had found that it was composed of a quantity of light polarised in an opposite direction, and proportional to that which was reflected, and of another portion not modified, which preserves the properties of direct light. This last portion he found to diminish at every new transmission of the ray, so that, by making the ray pass through a pile or bundle of parallel glass plates, the portion of light transmitted is all polarised in one direction, whilst that which is reflected is polarised in an opposite direction, and in this way the ray is decomposed into two oppositely polarised pencils, as in the case of double refraction.

In a subsequent memoir, read before the Institute on the 11th May 1811, Malus has presented this last result in a still more general form. Whenever, says he, we produce by any means whatever a polarised ray, we obtain necessarily a second ray polarised in a direction diametrically opposite, and these rays follow different paths. Light cannot receive this modification in one direction, without a proportional part of it receiving it in the opposite direction.

In continuing his experiments on the polarisation of light by reflection, he found that all bodies, whether opaque or transparent, polarise light under all angles, though for each of these bodies this phenomena has a *maximum* at a particular angle. He concluded, therefore, in general, that all light that had experienced the action of bodies by reflection or refraction contained polarised rays, whose poles are related to the plane of reflexion or refraction. This light has properties and characters which are not possessed by that which reaches us directly from luminous bodies. After measuring the angles of reflection under which the incident light is completely polarised by various different substances, he concluded that this angle, which was 52° 45′ for water, and about 54° 35′ for glass, *follows neither the order of refractive powers, nor that of dispersive powers, but that it is a property of bodies, independent of the other modes of action which they exercise over light.* After having determined the angles under which this phenomenon takes place from different bodies, water and glass, for example, he then endeavoured to ascertain the angle at which it took place at their separating surfaces, when they were in contact. He did not succeed, however, in determining this action; and he remarks, that the law, according to which this last angle depends on the two first, remains to be determined."

In his early experiments, Malus had announced that the metals did not polarise light at all, and afterwards that they polarised it in an incomplete manner. The ray which these surfaces reflected at all incidences was constantly susceptible of being divided into two pencils, when analysed by Iceland spar, though when the incidence was great one of the images became fainter, while the other increased in intensity; but this phenomenon was never sufficiently apparent to enable him to determine at what angle it is a maximum. Malus, however, overcame this difficulty in a very ingenious manner. He received upon a metallic mirror, a ray directly polarised, but in such a manner that the plane of reflexion made an angle of 45° with the rectangular poles of the ray. At very small or very great incidences it was always refracted in a single pencil by Iceland spar, but at a mean incidence it was completely depolarised, so that it could always be divided into two rays by Iceland spar. Hence he concluded that the difference between transparent and metallic bodies was, that the former refract all the light polarised in one direction, and reflect all that is polarised in the other, while metallic bodies reflect what they polarise in both directions.

In his theory of double refraction, Malus extended his observations far beyond the ordinary phenomena of Iceland spar, as observed by Huygens. He discovered what he has called the phenomena of extraordinary reflexion, at the second surface of a rhomb of Iceland spar. When a ray of light is incident upon this rhomb, it divides itself into two pencils within the crystal, and emerges in two pencils at the posterior surface. These two pencils, however, when they suffer reflexion at the posterior surface, are each divided into two pencils, and the single incident ray finally emerges in four pencils at the surface of incidence, excepting in the case where the ray is in the plane of the principal section.

The phenomena of multiplied and coloured images, observed in Iceland spar by Huygens, and afterwards studied by Benjamin Martin, Dr. Robison, and Mr. Brougham, did not escape the notice of Malus.* These phenomena seemed at first to form exceptions to the laws of double refraction; but he concluded that the multiplication of images arose from cracks or fissures within the crystal, and parallel to the great diagonals of the rhomb; and on this principle he explains the general cause of these phenomena. With regard to the brilliant colours with which these images are affected, and which vary in the most beautiful manner by the slightest inclination of the rhomb, Malus was mistaken in considering them as the colours of a plate of air. By a more precise examination of the crystals which produce these singular effects, Dr. Brewster afterwards proved that the multiplication of images arose not from a fissure, but from interrupting veins, or strata of calcareous spar, dividing the rhomb into two or more portions, and acting upon the transmitted rays at both of its surfaces; and he has shown that the brilliant colours are those which are polarised by the interrupting vein, and that they have no connection whatever with the Newtonian colours of thin plates.

The attention of Malus was likewise directed to the phenomena of double refractions in *Arragonite*, *Quartz*, and *Sulphate of Barytes*.[*] He considered the law of double refraction in calcareous spar, as representing accurately the phenomena in these and all other doubly refracting bodies; but though the experiments by which he was led to this general conclusion, were no doubt made with his usual care, yet it has been shown by Dr. Brewster that *Arragonite* and *Sulphate of Barytes*, have actually *two axes*, and that it is the general character of the great body of doubly refracting crystals to have two axes of double refraction.

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* *Theorié de la Double Refraction*, § 41, p. 194.

On the 19th of August 1811, Malus communicated to the Institute a memoir *Sur l'axe de refraction des Cristaux et des substances organisées*." By placing minerals and crystals of all kinds between two plates placed in such a manner that the second did not reflect the light polarised by the first, he found that they all depolarised the light, excepting those which crystallised in the form of the cube, or the regular octahedron. In applying the same mode of observation to various organized substances, whether vegetable or animal, he found that they all possessed this property of crystals. The substances which he tried, were the fibrous and transparent parts of the leaves and flowers of plants; the pellicles which cover the hazel; the fibres of silk and wool; white hairs, scales, horn, ivory, feathers, the skins of quadrupeds and fishes; shells, and the whiskers (fanon) of a whale. In concluding this memoir, Malus remarks, that these bodies are either composed of particles organised like crystals, or the phenomena which they exhibit depend on the general properties of reflected and refracted light, which he had previously discovered.

This distinguished philosopher promised to discuss this question in another memoir; but a premature death, which took place on the 7th February 1812, cut short his brilliant career, and deprived the sciences of one of their brightest ornaments.

The peculiar importance of the discoveries which we have been attempting to explain, will probably not be recognised to its due extent during the century which they adorn. The few individuals who have cultivated this profound branch of inquiry, and the few readers who are able to understand their labours, have no doubt fully appreciated the value of Malus's discoveries. But it is in a great measure in their consequences that posterity will be able to form a true estimate of their importance. Had the subject of double refraction and polarisation formed only a branch of physical optics, the splendour of its phenomena, and the beauty of its laws, must have assigned it a high rank among the objects of scientific inquiry; but its importance rises above all limits, when we consider it as an instrument of research, by which we can examine the structure and constitution of organised matter, and thus penetrate into regions which seemed to have been placed beyond the reach of human sagacity.

The brilliant success which attended the investigations of Malus, induced some of his colleagues in the Institute to pursue the same branch of optical inquiry. On the 11th August, 1811, M. Arago communicated to the Institute, a Memoir "On a Particular Modification which the luminous rays experience in their passage through certain transparent bodies."[†] He observed that when polarised light was transmitted through thin plates of sulphate, of lime, mica, and rock crystal, and afterwards analysed with a prism of calcareous spar, they exhibited the most beautiful complementary colours, analogous to those of Newton's scale. He found that there were two positions of the plate at right angles to one another, in which the crystal gave no colours, and depolarised no light, while the colours appeared in all intermediate positions. He found that the power of depolarising the different colours diminished with the thickness of the plate, and he succeeded in reducing mica to such a degree of thinness, that it had no power of depolarisation. In studying the same phenomena in sulphate of lime, he found that the colours depended upon some other cause besides that of the thinness of the plate; and in a plate of rock crystal, about 6 millimetres thick, he obtained the same result. M. Arago likewise detected the depolarising property in a piece of flint glass about three-fourths of an inch thick; and from this he concludes that the property of depolarising light, which seemed at first to be a good method of ascertaining the existence of double refraction, is no longer a sure test, as it is possessed by a piece of flint glass, which does not double the images.

In examining the coloured fringes seen by transmission through a thin plate of air, or any other transparent body, M. Arago discovered the very curious fact, that the brightest part of the transmitted rings was polarised in the same plane as the reflected pencil, and not in the same manner as the refracted pencil, as might have been expected. This phenomenon, however, arises from the reflexion of the light in the interior of the plates, which emerges along with the refracted pencil, so that it does not form any exception to the generality of the fact observed by Malus.

M. Arago has, we understand, recently obtained a very interesting result respecting the connexion between the inference of divergent light and the deoxidating effect of the invisible rays. When two portions of light interfere so as to destroy one another, the black spot where this destruction takes place has the property of deoxidation.

M. Arago, in conjunction with M. Fresnel, made some interesting experiments on the influence of polarisation on the interference of two portions of light. They found that in the same circumstances where two rays of ordinary light appear mutually to destroy one another by interference, two rays polarised in opposite planes do do not influence one another in any perceptible manner; but when the rays of light are polarised in the same plane, the phenomena of interference are exactly the same as with common light. They observed, also, that two rays originally polarised in opposite planes may be afterwards brought back to the same plane of polarisation, without acquiring the faculty of influencing one another; and that two rays polarised in opposite planes, and afterwards brought back to analogous polarisations, influence one another like natural rays, if they proceed from a pencil originally polarised in one single plane.

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[*] "Ce crystal," says he, when speaking of calcareous spar, "sera donc l'objet de nos principales recherches. Nous entendrons ensuite aux autres corps les resultats auxquels nous aura conduit l'examen de celui-ci; ce qui sera d'autant plus facile que, sans avoir recours à l'analogie nous *prouverons* d'avance par des *experiences directes l'identite* d'action de tous les corps qui refractent doublement la lumiere" *Theorie de la Double Refraction*, § 1. p. 97. And afterwards, "Je ferai voir dans les chapitres suivans que les *resultats sont les memes pour les autres substances*, en changeant la valeur des constantes qui entrent dans le calcul." Ib. § 17, p. 125. See also § 55, 56, 57, 58, and p. 242—258.

[†] This Memoir is published among those of the Institute for 1811, part i. p. 93—134. The author states that, since the reading of his memoir, he has "examined some optical phenomena more or less intimately connected with these which he has described, and which *show distinctly on what circumstances in the interior of crystals, depend those remarkable properties, which the rays acquire in traversing them.*" These new experiments, however, are not given in the Memoir; but the author promises such new "developments as will *complete the theory of this class of phenomena.*" The experiments, thus promised, have never been published, and the theory of this class of phenomena, has been nearly completed by the united labours of succeeding philosophers, continued through the long period of ten years.

As the researches of M. Arago on the colours produced by exposing crystallized plates to the action of polarised light, did not lead him to any general views, either respecting the laws of the phenomena, or the forces by which they are produced, a rich field of investigation was left open to the labour and ingenuity of future inquirers. M. Biot saw the extent and importance of the subject, and immediately directed to it all the ardour and ingenuity of his powerful mind. On the 1st of June, 1812, he communicated to the Institute his first memoir, *Sur des Nouveaux Rapports qui existent entre la Reflexion et la Polarisation de la lumiere par les Corps Crystallisés.* In this memoir, which occupies 145 pages, he has detailed the results of an immense number of experiments, made by means of a divided apparatus, and with a spherometer, constructed by M. Cauchoix, for measuring the thickness of thin plates. He determines what he supposes to be the axis of double refraction in Sulphate of Lime. He concludes that the axis of the partial polarisation of the laminæ is situated in this plane, and parallel to the direction which the axis of complete refraction has in the entire crystal. He composes empirical formulæ for calculating all the variety of tints which these laminæ produce at a perpendicular incidence. He shows that all the colours arise from the combination of two tints, which mix in different proportions, and which correspond to the two colours seen by reflexion and transmission in thin plates of air and other substances; and by comparing the tints with the thickness of the laminæ which produce them, he concludes that they are proportional to those of thin plates of air or glass, so that, by having the tint at one thickness, the tint at all other thicknesses could be determined from the colours and numbers in Newton's table. He next shows that plates of Rock Crystal follow the same laws as those of sulphate of lime; and he gives formulæ for finding the nature of the tints, when the polarised ray is inclined to the surface, on the supposition that the changes of colour which accompany a change of incidence, are analogous to those of thin plates. From all these results, he concludes, in general, that the polarisation of light in Sulphate of Lime and Rock Crystal, follows exactly the same law and the same periods as ordinary reflection in thin plates of air or glass, with this difference only, that the two classes of phenomena take place at different thicknesses.

In a second memoir, which M. Biot read to the Institute on the 16th June, 1812, he announces that he has found in the polarisation of light a law analogous to that of the conservation of living forces in mechanics. This law is nothing more than the fact, that the same tint is constantly produced by any number of laminæ combined, whatever be the order of the combination, provided only that their axes are parallel.

Desirous of referring these different phenomena to some general principle, M. Biot devised a theory for explaining them, which he laid before the Institute on the 30th of Nov. 1812, under the title of *Sur un nouveau genre d'Oscillation que les molecules de la lumiere eprouvent en traversant certains cristaux.* In this memoir, which fills a quarto volume of 371 pages, he takes it for granted that light consists of separate particles; and he endeavours to show that the phenomena of polarisation are produced by a succession of oscillations round their centre of gravity, which the particles of light experience from the action of attractive and repulsive forces, and that these oscillations go on to a certain depth in the crystal, after which the particles acquire a fixed polarisation, which arranges their axes in two rectangular directions He endeavours to determine the duration and velocity of these oscillations, and the law of the forces which produce them, and he attempts to show how we may at pleasure accelerate or retard these oscillations, or even destroy them altogether, or cause them to be performed in an opposite direction. In all these researches the author has shown much ingenuity and address; but we may fairly question the value of an hypothesis like this, devised in the infancy of a science, before its first principles even had been established, and when only a small portion of its leading facts had been discovered.

In a memoir read on the 27th Dec. 1813, M. Biot obtained analogous results from thin plates of Calcareous Spar and Arragonite, and he concluded from these observations, that the last of these minerals had one axis of double refraction and polarisation, like Calcareous Spar.

By far the most important of M. Biot's discoveries was that of two different kinds of double refraction and polarisation, which he found in Quartz and Beryl,* and which he distinguished by the names of *Polarization Quartzeuse*, and *Polarisation Berillée*, the first division containing rock crystal, sulphate of lime, sulphate of barytes, and topaz; and the second, calcareous spar, arragonite, apatite, beryl, and tourmaline. In those crystals which have the quartzy polarisation, the direction of the extraordinary ray is considered as produced by an *attractive* force, which draws it to the axis, and the phenomena are represented by an ellipsoid of revolution elongated at the poles: while in those that have the berillous polarisation, the deviation of the extraordinary ray is produced by a *repulsive* force which drives it from the axis, and the phenomena are represented by an ellipsoid of revolution flattened at the poles.

After the connexion between the optical structure and the chemical composition of minerals had been pointed out by Dr. Brewster, and he had discovered and communicated to the Royal Society a general law, relative to the connexion between the number of axes of double refraction and the primative forms of crystalized bodies, M. Biot laid before the Institute, on the 22d June, 1818, a Memoir "*Sur l'utilité des lois de la Polarisation de la lumiere pour reconnoitre l'état de cristallisation et de combinaison, dans un grand nombre de cas où le Systéme cris-*

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* These experiments are contained in two memoirs communicated to the Institute on the 15th May, and 26th Dec. 1814.

tallin n'est pas immediatement observable."[*] Having long before found some specimens of mica, with only one axis of polarisation, which he ascribed to *imperfect crystallization*, M. Biot examined a great number of different specimens of the same mineral, some of which had one axis, while the rest had two axes of different intensities. These different specimens were given to M. Vauquelin for analysis, and it appeared that those which had one axis contained a considerable quantity of magnesia, and that those whose axes had different intensities, had likewise different ingredients.[†]

A particular species of polarised tints was noticed by M. Arago, along the axis of rock crystal, and was carefully analyzed by M. Biot in his early memoirs. These tints differed in a very remarkable manner from those polarised by the crystal in other directions, and led M. Biot to another theory, as extravagant as that of the oscillation of luminous molecules, in which he ascribes the phenomena seen along the axis of rock crystal, to a continual rotation of the particles of light round their axes, produced by the action of the crystal. Some time afterwards, in the end of the year 1815, and the beginning of 1816, he and M. Seebeck discovered, about the same time, that an analogous property was possessed by a great number of fluids, such as the essential oils, and different solutions, some of which, according to M. Biot, like certain specimens of rock crystal, gave the particles a rotatory motion from left to right, while other fluids, like other specimens of rock crystal, turned the particles from right to left.[‡]

In a subsequent memoir, read to the Institute on the 22d September, 1818, entitled, "*Sur les rotations que certaines substances impriment aux axes de Polarisation des Rayons lumineux*," and occupying about 100 pages, M. Biot has resumed the same subject of rotatory polarisation as exhibited in rock crystal, oil of turpentine, sugar, and the vapour of oil of turpentine; and he has concluded, that the rotation of the luminous particles is reciprocally proportional to the square of the lengths of the fits, as determined by Newton. In obtaining this conclusion, he determines, by means of a red glass, which absorbs all but the red rays, the arch of rotation for the red rays corresponding to a thickness of one millimetre of rock crystal, and deduces theoretically from the old and imperfect division of the spectrum, the arch of rotation for all the other six colours. He then attempts to show that the same law of rotation is applicable to the fluids above mentioned, and that it ought to be the general law for all other substances that possess the rotatory property; and he concludes that the property of turning the particles of polarised light round their axes, resides in the ultimate particles of the solid or fluid; that it is necessary to the very existence of these particles;[§] and, consequently, that the phenomena are entirely independent of the mode in which the particles are aggregated.

In this, as well as in other memoirs, M. Biot assumes it as quite certain, that the polarised tints are the same as those of thin plates; an opinion which the subsequent inquiries of Dr. Brewster and Mr. Herschel have completely overturned; but, independent of this gratuitous assumption, there is a source of error in his fundamental experiment with the red glass, of which he probably was not aware. Dr. Brewster has shewn that with absorbent coloured media, the middle of the red space is sometimes absorbed, at other times the inner portion, and at other times the extreme portion. It is therefore of consequence to know, before the arcs of rotation are admitted as correct, whether the red glass transmitted the middle or the extreme portion of the red space, or if it transmitted the whole of the red rays without exception.

After the general laws of polarisation and double refraction had been investigated and published by Dr. Brewster in the *Philosophical Transactions* for 1818, M. Biot communicated to the Institute, on the 29th March, 1819, a memoir on the same subject. In this memoir, M. Biot transforms the mechanical law of double refraction and polarisation given by Dr. Brewster, in which the phenomena are referred to rectangular axes, into a law in which the phenomena are related to the apparent axes, or those passing through the centres of the two systems of rings; *but the two laws are absolutely the same.* M. Biot then proceeds to detail a variety of experiments on topaz, for the purpose of verifying the law of double refraction; and as these agree with it in a very remarkable manner, all the experiments of M. Biot must be considered as adding new evidence to the general law of double refraction and polarisation discovered by Dr. Brewster. Mr. Herschel has stated, in the *Philosophical Transactions* for 1820, that he found from experiment an expression of the law in relation to the apparent axes, similar to that which M. Biot had given; but he was not then aware, that both these laws were identical with the one previously given by Dr. Brewster. Those readers who wish to make themselves acquainted with the labours of M. Biot, will study them with more advantage in his *Traité de Physique*, tom. iv. than in the original memoirs; but we must warn them not to expect in that work any thing more than a few notices, and these, too, very imperfect, of the labours of contemporary philosophers.

The paper on the refractive power of the gases, which he published in conjunctoin with M. Arago, is one of much interest and value. The densities and refractive powers of *nine* gases were measured with great care in reference to the atmospheric air taken as unity. Oxygen had the least refractive power of them all, viz. 0 8616, and hydrogen the greatest, or 6.61436, which becomes 7.0335, if we use the density as measured by Berzelius.

M. Biot published, in 1809, a Memoir on the Mirage, or the phenomena of unusual refraction; but it is not marked by any very prominent or interesting results. He has treated the mathematical theory of these curious phenomena with his usual ability; and from a great variety of observations made on the sandy plains near Dunkirk, he has found that a difference of temperature, equal to two degrees of the centigrade thermometer, is sufficient to produce the inverted images of objects when seen over a smooth and extended surface. He has proved that the consecutive trajectories passing from the eye of the observer cut one another in their second branches, so as to form a caustic. All objects situated between this caustic and the horizon are invisible. All objects situated above the uppermost or limiting trajectory, are seen single; but all objects placed between the limiting trajectory and the caustic have two images, the uppermost of which is erect, and the lowermost inverted. Besides these various Memoirs of M. Biot, of which we have given a brief notice, he has published in the Journals many recent notices of interesting facts and observations, which it would be inconsistent with our plan to notice in the present brief history of the science.

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[*] This Memoir, by a strange anachronism, which has a tendency to mislead the reader with respect to dates, is printed in the Memoirs of the Institute for 1816, p. 275—347, though it was neither written nor read till 1818.

[†] See the *Edinburgh Philosophical Journal*, vol. v. p. 1, for an account of the history of this class of experiments. See also the *Journal of the Royal Institution*, vol. iv. p. 112, and the *Journal de Physique* for Oct. and Nov. 1817, vol. lxxxv. p. 333 and 334.

[‡] See Biot's *Traité de Physique*, tom. iv. p. 539 and 499.

[§] "Faculté qu'elles ne peuvent perdre que lorsqu'*elle cessent d'etre elles-memes* par leur decomposition." *Mem. Instit.* 1818.

Contemporary with the labours of MM. Arago and Biot were those of Dr. Brewster. In his *Treatise on New Philosophical Instruments*, published in the beginning of 1813, he has given an account of a series of experiments on refractive and dispersive powers, in which he was led to several new results. He found that Chromate of lead, Realgar, (to which he has since added Ruby silver, and Octohedrite,) have all a greater refractive power than Diamond, which had hitherto stood before all other bodies;—that the Diamond, Phosphorus, and Sulphur, have their high refractive powers in the order of their inflammabilities;—that fluor spar and cryolite have lower refractive powers than all solid substances, and the lowest dispersive powers of all bodies; and that all doubly refracting crystals have a double dispersive power. With the view of improving the achromatic telescope, he made a variety of experiments on the action of different bodies on the differently coloured rays. He found that oil of cassia, a fluid of remarkable refractive and dispersive power, had the least, and sulphuric acid the greatest action upon green light; that a *tertiary spectrum* is formed when prisms of the same substance and different angles correct one another's dispersion by the inclination of one of them; and that refraction without colour could be produced, and consequently achromatic combinations effected, by prisms and lenses of the same kind of glass.

From these inquiries Dr. Brewster proceeded, in the year 1812, to the subject of the polarisation of light, which had received such an impulse from the discoveries of Malus. He found that the agate impressed upon a transmitted ray a polarisation opposite to that which it would have received by reflexion; that the polarisation of a pencil of light could be apparently destroyed by subsequent transmission through almost all mineral substances, and even some animal and vegetable ones; and that thin plates of mica and topaz exhibited the most beautiful complementary colours when exposed to polarised light; that light is partially polarised by reflexion from polished metals; and that the light reflected from the clouds, and the blue light of the sky, and the light of both the exterior and the interior rainbows, are all polarised. In the discovery of the polarised tints of crystalline plates, however, Dr. Brewster was anticipated by M. Arago, and in that of depolarisation and of the action of metallic surfaces by M. Malus.

In continuing these researches, he discovered the beautiful system of elliptical coloured rings, which are seen both by reflexion and transmission, by looking through topaz in two directions, and which he found under different modifications in various other bodies. These experiments, with others on the agate and the depolarisation of light, were read before the Royal Society of London, on the 23d October, 1813, and printed in their Transactions for the following year. About the same time he was led to the discovery of the polarisation of light by oblique transmission through bundles of *crystallized* or *uncrystallized* plates; but though he was also anticipated in this discovery by Malus, in so far as relates to uncrystallized plates, yet in his paper on this subject, read to the Royal Society of London on the 27th Jan. 1814, and printed in their Transactions of the same year, he has determined the law of the phenomena, which had escaped the notice of Malus, and has shown that, with a given light, the number of plates required to polarise the transmitted rays at different angles are to one another as the co-tangents of these angles; the light of an ordinary candle, at the distance of ten or twelve feet, being completely polarised at an angle of 66° 43′ by *eighteen* plates of crown glass.

In the beginning of April 1814, Dr. Brewster communicated to the Royal Society of London his experiments on the production of the polarising structure in glass by heat, and also by cooling it rapidly. This paper was read on the 19th May, 1814; and was immediately followed by another on the structure of Prince Rupert's drops, which are formed by throwing drops of melted glass into water. A very extensive series of experiments on the depolarising structure of animal and vegetable bodies, by the same author, was read to the Royal Society on the 15th Dec. 1814.

On the 3d of January, 1815, Dr. Brewster discovered that all the *phenomena of polarisation and double refraction could be communicated to soft and indurated jellies by simple pressure*. This paper was read to the Royal Society on the 19th Jan. 1815.[*]

Hitherto the laws of the polarisation of light by reflexion were entirely unknown; and Malus had concluded that it was a property of bodies independent of their other modes of action. Having conceived, however, an opposite opinion, Dr. Brewster began, in 1811, an extensive series of experiments, to determine the angles of polarisation, not only from the surfaces of bodies, but also from the separate surfaces of different media. In this inquiry many difficulties were experienced from irregularities in the action of glass; but the cause of these having been detected, he succeeded in referring all the measurements to the simple law, *That the index of refraction is the tangent of the angle of polarisation*, which gives the angle of maximum polarisation, not only for the first and second surfaces of all transparent bodies, but also for the separating surfaces of different media. When this law is put into a geometrical form, it follows, that whenever a ray of light is polarised by reflexion, the reflected ray forms a right angle with the refracted ray; and that the sum of the angles of reflexion and refraction is a right angle; or, reckoning from the surface, that the angles of reflexion and refraction are equal. The very same law is applicable to the differently coloured rays, each of which is polarised at an angle, whose tangent is the refractive index appropriate to each; and hence is deduced the reason why a portion of unpolarised light exists at the maximum polarising angle of all substances. Our author then goes on to show, that a pencil of light may be completely polarised by two, three, four, or more reflexions at angles above and below the maximum polarising angle, a greater number of reflexions being necessary as the angle recedes from that which gives a maximum polarisation. He concludes from various arguments, that every ray of light polarised by reflexion has been acted upon by the refracting force before it has suffered reflexion; for upon this supposition it follows, that the real polarising angle is 45° for all bodies whatever; and in proceeding to consider the action of transparent surfaces, when they produce total reflexion, he shows, that these surfaces polarise the light in two opposite planes, in the same manner as Malus had found to be the case with polished metals.

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[*] These results respecting the production of polarisation by pressure, were transmitted to M. Biot on the 24th Jan. 1815. He immediately communicated them to the Institute; published an abstract of them in the *Bulletin de la Societé Philomathique* for March, 1815; and in a letter written about the end of Feb. 1815, he sent to Dr. Brewster a kind of theory of the phenomena. Notwithstanding these separate acts, he published a paper in the same *Bulletin* for April, 1816, making the date of Dr. Brewster's discovery nearly a whole year later than the date of the letter in his possession; and it was not without the greatest trouble, that he was brought to acknowledge, in the *Bulletin* for Jan. 1821, that he had forgotten for more than *twelve months* a discovery in his favourite science, of which he himself says, "*Il suffit d'enoncer ce resultat, pour faire sentir combien il est remarquable*" This acknowledgment would have set the matter at rest, had it not contained numerous inaccuracies, which render it necessary to refer the reader to the *Bulletin de la Societé Philomathique*, 1815, p. 44; 1816, p, 49, 50; and 1821, p. 15, 16; and to state, along with the reference, that, in the paper last quoted, *plusieurs mois* means at least ten months, and *quelques jours* at least *seventy-seven* days.

The effect of heat in producing the polarising structure in glass had been discovered and described by Dr. Brewster early in 1814; but in the summer of 1815 he was led to observe a series of unexpected phenomena produced by that powerful agent; and he has investigated at great length the laws by which these phenomena are regulated, in his paper "*On the Properties of Heat as exhibited in its propagation along Plates of Glass*," which was read before the Royal Society, on the 11th January, 1816.* When the edge of a thick plate of glass is laid on a bar of hot iron, the heat gradually propagates itself along the plate, and its path is marked by the most beautiful fringes of polarised light; but no sooner has the heat entered the plate of glass, than similar fringes appear on its upper edge, *where there is no heat at all.* After a certain period, the whole surface of the glass is covered with the coloured fringes, which are arranged in two similar polarising structures at the edges, separated by two dark lines or axes from an opposite structure in the middle. When the glass is removed from the iron, the fringes gradually disappear, and are extinguished when the heat is uniformly diffused over the glass. If the plate of glass is made very hot in boiling oil, and is then allowed to cool with its edges against a plate of cold iron, it will exhibit in a fainter degree the fringes above described; but they are now all reversed, the middle structure having the same character as the external structures had formerly, and *vice versa*. If, when a plate of glass is covered over with the polarised tints, it is suddenly cut in two by a diamond in the direction of its length, the whole structure is instantly changed, and each piece has the same properties and structure as the whole, exactly like a portion detached from the end of a magnet. The same properties he found in muriate of soda, fluor spar, obsidian, semi-opal, horn, tortoise-shell, and various animal and vegetable bodies. The tints thus developed by heat follow the same laws as those in regularly crystallized bodies, and exhibit, by their being made to cross one another, and by other modifications, a series of the most brilliant phenomena within the whole range of optics. In pursuing these experiments, Dr. Brewster found that when the plate of glass was made red-hot, and then rapidly cooled, it exhibited the same coloured fringes, a discovery which had also been made by Dr. Seebeck of Nuremberg, but without any analysis of the phenomena. The laws of these phenomena were afterwards investigated by Dr. B. and he has shown how to calculate them all from general formulæ.

In the beginning of November, 1815, Dr. Brewster discovered that glass, and all other solid substances, received the polarising structure by compression, and that compression and dilatation developed the two opposite polarising structures. These effects are well displayed by bending a large plate of tolerably thick glass, and exposing it to polarised light. The whole thickness of the plate will then be seen covered with two sets of fringes separated by a dark neutral line, the positive set being produced by the compressing, and the negative set by the dilating force. The same effects are developed in fluor spar, muriate of soda, and all bodies without double refraction; and some time afterwards, Dr. Brewster discovered that double refraction and polarisation could be communicated by pressure to all doubly refracting crystals whatever. These results are contained in two memoirs, the first of which was read on the 29th February, 1816, and the second on the 17th November, 1816.

Passing by his papers on a new species of coloured fringes; on the colours of mother-of-pearl; on the multiplication of images, and the colours which accompany them in Iceland spar; on the action of transparent bodies on the differently coloured rays; on the structure of the crystalline lens in fishes and quadrupeds; and on the mathematical laws which regulate the distribution of the polarising force in plates, tubes, and cylinders of glass, as being unsusceptible of a brief analysis,—we shall proceed to notice his discovery of the production of the complementary colours by the successive reflexion of polarised light between two plates of gold or silver.

On the 7th February, 1815, while examining the action of metals upon light, Dr. Brewster discovered that, when this light suffered one or more reflexions from plates of silver or gold, it exhibited all the complementary colours of crystallized laminæ. The colours rose in Newton's scale as the number of reflexions was increased; and the influence even of one reflexion was distinctly seen from the effect which it had in modifying the tint of a plate of sulphate of lime. When the axis of a positive or attractive crystalline plate was placed in the plane of reflexion, the light which it polarised, rose in the scale by the additional tint polarised by the metal; and when a negative or repulsive plate had the same position, its own tint was diminished. Analogous results were obtained with steel, mercury, the fusible metal, platinum, rhodium, and the metal for speculums, but with some modifications. When common light underwent successive reflexions between metallic plates, he found that one of the pencils was absorbed, and consequently all the light polarised in one plane after a certain number of reflexions. This number, however, was much greater for gold and silver than for any of the other metals.[*]

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* See *Philosophical Transactions*, 1816, p. 46—115

In the different Memoirs of which we have given a short notice, our author considered principally those branches of the polarisation of light which related to the superficial action, or the superinduced properties, of crystallized bodies. His attention, however, had frequently been directed to the phenomena of regular crystals; but it was not till he had devoted to the subject the labours of nearly three years, that he succeeded in reducing under a general law all the complex phenomena of doubly refracting crystals. This law, and the steps by which it was discovered, are fully explained in his paper *On the Laws of Polarisation, and double refraction in regularly crystallized bodies*, which was read before the Royal Society of London, on the 15th January, 1818.

The Huygenian law was then considered the universal law of double refraction, and all crystals were supposed to have one axis. Malus, as we have already seen, had concluded that Arragonite and Sulphate of barytes had one axis of double refraction, like Quartz and Calcareous spar. M. Biot had maintained that Arragonite, Sulphate of barytes, Sulphate of strontian, Sulphate of lime, Feldspar, and Topaz, had one axis of double refraction; and having investigated the laws of polarisation for Sulphate of lime, he concluded that these were the laws of polarisation for all other bodies. (See p. 589.) At the very commencement of this inquiry, Dr. Brewster found that all the above-mentioned crystals examined by Biot had *two axes* of double refraction. He discovered that by far the greater number of crystals had two axes of double refraction; and by projecting the coloured rings, and measuring the tints which they exhibit at various angular distances from the axes, he was led to a general principle which embraces all the phenomena, and extends to the most complex as well as to the most simple development of the polarising forces. This general principle is in no respect an empirical expression of the facts which it represents, nor is it supported by any empirical data. Founded on the principles of mechanics, it is a law rigorously physical, and enables us to calculate all the tints, &c. of the coloured rings, and all the phenomena of the extraordinary refraction, with as much accuracy as we can compute the motions and positions of the heavenly bodies. This general law, when applied to the polarised tints, is thus expressed: *The tint produced at any point of the sphere, by the joint action of two axes, is equal to the diagonal of a parallelogram whose sides represent the tints produced by each axis separately, and whose angle is double of the angle formed by the two planes passing through that point of the sphere and the respective axes.* When the law is applied to the phenomena of double refraction, it may be thus expressed: *The increment of the square of the velocity of the extraordinary ray produced by the action of two axes of double refraction, is equal to the diagonal of a parallelogram whose sides are the increments of the square of the velocity produced by each axis separately, and calculated by the law of Huygens, and whose angle is double of the angle formed by the two planes passing through the ray and the respective axes.* When the two rectangular axes are of equal intensity and of the same character, the preceding law gives the very same results as the law of Huygens does for one axis placed at right angles with the other two. When the crystal has three equal rectangular axes, their forces are in equilibrio in every part of the sphere, and there is neither double refraction nor polarisation. When the first of these laws is applied to the mysterious action of sulphate of lime, with the origin and classification of which M. Biot has been so much perplexed, and which he has represented by complicated and empirical formulæ, the whole mystery disappears, and all the diversified and capricious variations of tint which he had ascribed to secondary forces, become the legitimate and calculable results of two axes of double refraction.

In the course of researches embracing the examination of such a great number of crystals, our author was led to many general results that were indirectly connected with the leading object of investigation. He discovered the general law which subsists between the number of axes of double refraction, and the primitive forms of minerals; he pointed out the advantage which mineralogy would derive from the optical characters of minerals, and announced the important connection which existed between the optical structure and chemical composition of crystallized bodies.

In a paper on Circular Polarisation, as exhibited in the Amethyst, which appeared in the *Edinburgh Transactions*, he has shown that this mineral combines the opposite structures of the two varieties of quartz, which turn the planes of polarisation of the rays from right to left, and from left to right; he has shown how these opposite structures destroy and modify one another; he has examined the distribution of the colouring matter in relation to this structure, and in that paper, and elsewhere, he has demonstrated, that the property of circular polarisation does not belong to the ultimate particles of matter, as Biot maintained, but that it may be entirely removed from quartz by melting it.

On the 17th October, 1818, our author communicated to Sir Joseph Banks his paper "*On the Laws which regulate the absorption of polarised light by doubly refracting crystals.*" Hitherto it had been only observed, that across the point of a singly refracting prism of tourmaline, made so thin as to give the two images the direct light of a white object, had not exactly the same tinct, an effect which was attributed to the absorption of some of the rays;[†] but Dr. Brewster discovered that in a great number of coloured crystals, both with one and two axes, such as, calcareous spar, emerald, beryl, ruby, quartz, amethyst, idocrase, phosphate of lead, phosphate of lime, and mellite, having one axis of double refraction; and in nearly thirty crystals with two axes, polarised light was absorbed, according to regular laws, depending on the position of the ray in relation to the axis of the crystal; and that this singular property was always accompanied with another, viz. that the two pencils formed by double refraction in these crystals had different colours, a phenomenon which is likewise related to the axis of double refraction. The difference of colour is nothing in the direction of the axis, and gradually increases and becomes a maximum at right angles to it. The two classes of phenomena now described are particularly splendid in super-acetate of copper, augite, dichroite, Brazilian topaz; and the two different colours of dichroite observed by Cordier, when it is examined along the axis of the prism, and perpendicular to it, have been traced by Dr. Brewster to its two apparent axes of double refraction, from each of which there issues at right angles to one another two streams of blue and yellowish-white light. In some crystals of augite he has found these colours to be the *brightest green* and the *deepest scarlet*, and he has shown that the property of absorption may be modified in Brazilian topaz by heat, and even communicated to crystals which do not naturally possess it.

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[*] Although these experiments on metallic polarisation were made early in 1815, yet Dr. Brewster's memoir has not yet been published. Having had occasion to write M. Biot on a matter of business on the very day upon which he made this discovery, he communicated it to him in that letter. Not content with verifying the experiments, M. Biot pursued the subject, obtained, of course, many of the results which Dr. B had obtained, and published Dr. B's results and his own in the 4th volume of his *Traité de Physique*. For this reason, and for others which will be stated in the Memoir itself, it has remained for seven years in MS.

[†] The absorption of certain rays of direct light was long ago discovered in several *tourmalines*, and in the crystals of *palladium*, by Dr. Wollaston, who found that they were generally of a *deep red* colour, when viewed in the direction of the axis, and of a *yellowish green*, when viewed in a transverse direction; whereas, in some crystals, they are *greenish* in the first direction, and *reddish* in the second. See *Philosophical Transactions*, 1804, p. 428. The Marquis de Drée made an analogous observation on the tourmalines in his collection, but in what year I cannot find. M. Cordier observed a similar fact in *Iolite* or *Dichroite*, (See *Bulletin de la Soc Phil.* 1809, vol. i. p. 352,) and the Count de Bournon remarked a similar thing in a variety of specimens of *mica*, where the colours were often very different. *Catalogue*, &c. Lond. 1812, p. 121. These facts prove that the absorption of light by crystals has been long known,

In all the experiments which had hitherto been made, no other bodies but the gases had been found which possessed a lower refractive power than water and ice, whose indices of refraction were 1.3358, and 1.308. Having had occasion to examine the remarkable physical properties of a vegetable siliceous concretion called *Tabasheer*, which is found in the joints of the bamboo, Dr. Brewster was led to measure its refractive power, and obtained the very remarkable result, that its index of refraction was 1.1115; displaying an action upon light far below that of all solid or fluid bodies, and intermediate between water and the gases. The absolute refractive power, when estimated in reference to its specific gravity, was 976.1, whereas the lowest formerly observed, viz. that of sulphate of barytes, was 3829.4. This singular substance exhibited also the strange property which is explained in Dr. Brewster's memoir on the subject, of assuming white opacity when it had absorbed a small quantity of water, and becoming almost perfectly transparent when it was saturated with that fluid.

From all the experiments which had hitherto been made on the polarisation of light by Malus and Biot, it was concluded that the reflecting power of crystallized bodies extended beyond the limits of the polarising forces, and that the forces which produce extraordinary refraction begin to act only upon the rays after they have penetrated the surface of the crystal.* Dr. Brewster, however, was led to doubt this opinion; and, on the 25th February, 1819, he communicated to the Royal Society his paper "*On the action of crystallized surfaces upon light.*" In the first section of this paper, which treats of the effects produced upon transmitted light by a change in the mechanical condition of the surfaces of crystals, he shows that either the ordinary or the extraordinary image may be extinguished at pleasure in any doubly refracting crystal, and the crystal converted into a singly refracting crystal, like certain specimens of agate. In the second section he establishes the remarkable fact, that the angle of maximum polarisation varies in the same surface of calcareous spar from 57° 14′ to 59° 32′, according as the short or the long diagonal is in the plane of reflexion; and he shows that the ray is polarised in the plane of reflexion only when that plane coincides with the short diagonal; but that, in every other position of the plane, from 0° to 180° of azimuth, there is a change in the direction of the polarisation, varying from 0° to 180°.

The great utility of the polarisation of light appears nowhere more conspicuous than in the information which it conveys to us respecting the structure of mineral bodies. In examining, by its agency, the crystals of Faröe Apophyllite, Dr. Brewster discovered, in 1817, the singular tesselated structure of this mineral; and, in repeating the same experiment more recently, with finer specimens, he has detected a structure through the faces of the prism resembling more that of an organized body than of a piece of dead matter. Forms unknown in crystallography occupy the central portion of the figure, and on each side of it particles of similar properties take their place at similar distances, now forming a zone of uniform polarising force, now another increasing to a maximum, and now a third descending in the scale by regular gradations. The boundaries of these corresponding though distant zones are marked

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and since tourmaline was known to be a doubly refracting crystal, and to polarise the two images, it was equally clear, that the light so absorbed must be polarised light. In his *Traité de Physique*, tom. iv. p. 313, M. Biot remarks, "that the two images of a white object seen across the *thinnest part* of a prism of tourmaline are not of the same colour. The ordinary one, which ought to disappear at a greater thickness is yellowish green, and the extraordinary one, which ought to remain, is sensibly white." "The *whiteness* of the persisting image when the other is already *coloured*, shows that this phenomenon does not proceed from an inequal repartition of the molecules between the two refractions, the ordinary and the extraordinary, as one might be tempted to believe at first sight; for then the persisting image ought to have a colour complementary to the other. The alteration in this last one, therefore, is posterior to the division of the light between the two refractions, and hence it results that the blue and violet molecules which are first wanting in this image, are more easily absorbed by the substance of the tourmaline when they are polarised parallel to its axis, than when they are perpendicularly." From this passage it appears, that M. Biot observed, that at very small thicknesses of tourmaline, the ordinary image, which entirely disappears at a greater thickness, has some of its blue and violet rays more easily absorbed in the direction of the axis than perpendicular to it, the extraordinary image not being affected at all. Now, if this experiment has any thing to do with the phenomena of the absurption of polarised light, as discovered by Dr. Brewster, or if it contains any thing beyond the observations of Wollaston and Bournon, M. Biot was long ago anticipated in his observation by our author, who observed the same thing repeatedly in plates of *agate* passing into the state of chalcedonous quartz; in *carbonate of barytes*, where the two images are distinctly seen, the one being white, and the other brownish red, (*Edin. Trans.* vol. vii. p. 289.) and in thick pieces of *mica*, where one of the two pencils was *entirely extinguished*,) *Phil. Trans.* 1814, p. 194, 225) but he could not tell whether the light was reflected or absorbed. In like manner, M. Biot had no reason to say that the violet rays were absorbed, as they might as well have been scattered by reflexion at the junction of the elementary prisms of the tourmaline. Hence, it is quite evident, that M. Biot was entirely unacquainted with the absorption of polarised light when he wrote his *Traité de Physique*.

* "Il parait, et ceci est encore bien constaté par mes experiences, il parait dis je que cette premiere reflexion s'opere hors de la limite des forces polarisantes des cristaux. Biot's *Tratié de Physique*, tom. iv. 339. Malus bad long before stated the same fact, and even in more explicit terms, in his *Théorie de la Double Refraction*, p. 240, 241.

with the greatest precision, and their parts as nicely adjusted as if some skilful workman had selected the materials, measured the spaces they were to occupy, and finally combined them into the finest specimen of natural mosaic. This compound structure sets at defiance all the usual laws of crystallization, and must ultimately lead to the introduction of some new principle of organization, of which crystallographers have at present no conception.

The experiments made by Dr. Seebeck of Nuremberg, on the polarisation of light, are very few in number, and are contained, so far as we know, in Schweigger's *Journal* for April, 1813, and December, 1814. M. Arago, in his early experiments, in 1811, had remarked the polarising structure in thick pieces of flint glass, and Dr. Brewster had done the same in 1812, with some thick pieces of unannealed plate glass. In Dr. Seebeck's first paper, which appeared in April, 1813, he describes the coloured figures which are seen in cubes and cylinders of glass. The effects, he says, were best observed in cubes of 1¾ of an inch, and better in white than in yellow glass. In cubes of an inch only, they were indistinct, nor were they produced by fluor spar, rock salt, or any kind of liquids. The only result of these experiments, therefore, is, that the polarising action which M. Arago and Dr. Brewster had previously observed in pieces of glass, is regular when the glass has a regular shape. In his paper of Dec. 1814, he shows that when a plate of glass is made red-hot, and set upon its edges to cool, it acquires at the parts which cool first, a series of coloured fringes, which spread over the whole plate, and the structure which produces them remains permanently fixed in the glass. M Seebeck obtained similar results from pieces of borax melted and rapidly cooled, pieces of muriate of soda rapidly dried, and plates of gum arabic quickly evaporated. These experiments, however, were long posterior to those of Dr. Brewster on the effects of heat upon glass, and on the structure of melted glass cooled in water, or Prince Rupert's Drops, to which, in February, 1814, he communicated the polarising structure by heat, and removed it by slow cooling.[*] Dr. Seebeck made no observations on the nature of the forces by which these phenomena were produced, nor gave any development of the phenomena which he observed.

In the course of these researches, Dr. Seebeck was led, in the beginning of January, 1816, to the discovery of polarised colours in certain essential oils, when placed between two transverse piles of glass plates; so that he has a parallel claim with M. Biot to this curious discovery, which, though communicated by the latter to the Institute on the 23d and 30th October was not published till the appearance of the *Bulletin da la Soceté Philomathique* for Dec. 1815, which, at the earliest, must have been in January, 1816.

In the month of March, 1815, Dr. Seebeck likewise discovered, in tourmaline, the same property of single refraction above certain thicknesses, which Dr. Brewster had, in 1812, discovered in the agate, and in 1813 in mica, carbonate of barytes, and mother-of pearl. M. Biot had discovered the same property in the tourmaline in Dec. 1814, but did not publish it till May 1815, in the *Annales de Chimie* of that month.

M Seebeck had likewise the merit of observing the coloured rings along the axis of Iceland spar, in Dec. 1815, a phenomenon which Dr. Brewster had discovered in beryl, ruby, &c. in 1813, and which Dr. Wollaston had observed in Iceland spar in 1814. M. Biot observed the same fact in Iceland spar, in Nov. 1815; and in a note in his *Traité de Physique*,[†] he adjusts his account with Dr. Seebeck, leaving the balance of a month in favour of himself, although he had in his possession a letter from Dr. Brewster, informing him of Dr. Wollaston's having shown him that same phenomenon in 1814; but neither the name of Dr. Brewster, as the discoverer of the same rings in beryl, nor that of Dr. Wollaston, who had such a decided priority over the French philosopher in the discovery of them in Iceland spar, are once mentioned.[‡]

M. A. Fresnel, engineer of roads and bridges, has pursued with remarkable success some of the most difficult inquiries in optics, and has rivalled, if not surpassed his colleagues in the Institute in the value of his discoveries.

In a series of memoirs presented to the Institute of France, in the years 1817 and 1818, M. Fresnel has given an account of a set of interesting experiments, by which he has discovered the connection between the phenomena of ordinary polarisation and those which are seen along the axis of rock crystal, and through particular fluids. Having arranged transversely to one another two prisms of glass, each of which gave two total reflexions to an incident polarised ray, he placed between each prism a crystallised plate parallel to the axis, that gave the ordinary complementary colours, so that its axis formed an angle of 45° with each of the rectangular planes of reflexion. He then found, that the ray transmitted across this system exhibited phenomena analogous to those seen along the axis of rock crystal. He determined the conditions which were necessary, in order that the apparent rotation of the planes of polarisation should be of an opposite nature; and he has shown, that the modification thus impressed upon light may be compensated by its transmission through a certain thickness of oil of turpentine, depending on the thickness of the crystalline plate. The considerations by which M. Fresnel was led to this interesting discovery were founded on the application of the law of interferences, discovered by Dr. Young, to the light which passes through doubly refracting media. Dr. Young had, in the year 1813, pointed out this happy application of his law to the phenomena of polarised light; and it has been completed by M. Fresnel, who has introduced into it the conditions dependent on the state of polarisation, and by determining on the principles of mechanics, the resultant of any number of luminous undulations.*

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[*] As we have not seen the Papers of Dr. Seebeck, we have collected the account of the first from an abstract of it in the Quarterly Review, and from a notice of it sent us for our information, and at our request, by an eminent philosopher who had read it with care. The account of the second is gathered from M. Biot's notice of the experiments which it contains, in his *Traité de Physique* tom. iv p. 573, where the history of this class of phenomena is most incorrectly given.

[†] Tom. iv. p. 542.

[‡] It is a circumstance equally strange, that in no part of these discussions about coloured rings, and indeed in no part of his capacious volume on polarisation, has M. Biot ever mentioned the remarkable *double system of coloured rings* discovered by Dr. Brewster in *Topaz*, and represented in various plates in the *Phil. Trans.* for 1814, although these plates have been in M. Biot's possession since the autumn of 1814. In that work *Topaz* is actually given as a crystal with one axis; and hence it follows, that M. Biot considered a double system of rings as compatible with a single axis of double refraction.

The Academy of Sciences having chosen the inflexion of light as the subject of their physical prize for 1818, it was adjudged to M. Fresnel for his discoveries on this subject. Instead of receiving the fringes on a white surface, as had hitherto been done, M. Fresnel examined them directly with an eye-glass furnished with a micrometer. In this way he found that a beam of light suffered a less degree of inflexion in proportion to the distance of the inflecting body from the point of divergence; and that the *successive positions of the same fringe* were not in a straight line, but form a curve, whose concavity is turned towards the inflecting body. These curves, as belonging to the different orders of colours, are all hyperbolas, having for their common foci the radiating point, and the edge of the inflecting body. M. Fresnel likewise found, that all bodies produced the same degree of inflexion, as had been determined long ago by Dr. Brewster, who examined the effects of platina, diamond, gold leaf, and evanescent films of all kinds, placed not only in air, but in various refractive media of greater and less refractive density than themselves. M. Fresnel and Dr. Young had ascribed the exterior fringes to the interference of the direct rays with rays reflected from the margin of the inflecting body. M. Fresnel, however, has since found that this is not the case, and now admits that the rays which pass at a sensible distance from the inflecting body are made to deviate from their primitive direction, and concur also in the production of the coloured fringes. These important discoveries, independent of their own value, are considered by their author as inexplicable by the Newtonian theory of emisssion of luminous particles, while they are directly deducible from the Huygenian theory of undulations.

M. Fresnel is also said to have made an important discovery relative to the laws of double refraction in crystals with two axes. He has found, that the ordinary ray, which was always supposed to follow the law of the sines, undergoes variations of velocity and refraction, analogous to those of the exraordinary ray, but confined within less extended limits. This new property, and the former phenomena of the extraordinary ray, he is said to have referred to compound ellipsoids, by which all the phenomena may be accurately represented.

About this time, M. Fraunhofer of Benedictbaiern, in Bavaria, made a series of interesting discoveries respecting the prismatic spectrum, and the inflexion of light. His observations on the spectrum were, we believe, first published in the Memoirs of the Academy of Bavaria for 1814 and 1815, and also in a separate pamphlet, entitled, *Bestimmung des Brechungs—und Farbenzerstreuungs—Vermogens verschiedener Glasarten*; and his experiments on the inflexion of light have been published more recently, but without any date, under the title of *Neue Modifikation des Lichtes*. As these papers are not susceptible of a brief abstract, we must refer, for an account of the discoveries they contain, to our Chapters on CHROMATICS and INFLEXION.

Among the important inquiries of this period, we must rank the observations on the spectrum, made by M. Berard of Montpellier, and Dr. Morichini of Rome. In repeating the experiments of Dr. Herschel on the heating powers of the prismatic colours, M. Berard obtained the same results in general; but he concluded that the maximum of heat was at the very extremity of the spectrum, and not beyond it. When the ball of his thermometer was entirely out of the red rays, he found that the temperature above that of the surrounding air was only one-fifth of what it was when the ball was entirely covered with the red light. M. Berard conceived the ingenious idea of ascertaining if these properties existed in the two pencils formed by double refraction; and having made a ray of the sun's light pass through a prism of Iceland spar, he examined carefully the two spectra which were formed. In this way he ascertained that the phenomena were exactly the same, the chemical and the heating rays being diffused over both spectra. M. Berard next attempted to determine if the invisible heating rays were polarised like the luminous ones by the action of the crystal, and by employing the apparatus of two transverse reflectors of glass, he found this to be the case, the thermometer always ceasing to be affected when the polarised visible rays ceased to be reflected from the second glass.

The experiments of Dr. Morichini on the magnetising property of the violet rays, are not less important. This ingenious and respectable physician, at the season of the year when the light of the sun is most powerful at Rome, formed the coloured spectrum by means of a prism, and having collected the violet rays in the focus of a convex lens, he moved the lens parallel to an unmagnetised steel needle, placed in its focus, and carried the focus of the violet rays from the middle of one half of the needle to the extremities of that half, and always in the same direction, without touching the other half. By continuing this operation nearly an hour, the needle was magnetised, and had perfect polarity. This remarkable experiment was repeated by Carpi. and Ridolfi, and in the presence of Sir H. Davy, Professor Playfair, and other English philosophers, who placed the most implicit confidence in the results. M. Berard failed in obtaining the same results at Montpellier. In some cases the needles appeared to be magnetised, and in others no effect was produced.

The science of optics had now the advantage of numbering among its cultivators one of the most accomplished mathematicians of the present age. Attracted to the study of polarisation and double refraction by the brilliancy of its phenomena, Mr. Herschel pursued it with zeal and ardour, and published his first researches in the *Philosophical Transactions* for 1820, in a paper entitled, "*On the action of Crystallised Bodies on homogeneous light, and on the causes of the deviation from Newton's Scale in the tints which many of them develop on exposure to a polarised ray.*"† The deviation of the polarised tints of different crystals, from the colours in Newton's scale, which was first pointed out by Dr. Brewster, attracted Mr. Herschel's peculiar attention, and having observed that this deviation did not arise from any irregularity of structure, but occurred in the most perfect specimens, he was induced to inquire into the cause of the phenomena. This deviation being enormous in tartrate of potash and soda, Mr. Herschel studied it particularly in this salt, and was thus led to the law of the phenomena. He found that the inclination of the resultant axes was different for different rays of the spectrum; or, what is the same thing, that the apparent axes of double refraction differ in their position in the same crystal for the differently coloured rays, being dispersed in one plane over an angle more or less considerable, according to the nature of the substance. In many crystals the extent of this dispersion was comparatively trifling, while in others it was so enormous, that almost every trace of the Newtonian scale of colour was obliterated. In tartrate of potash and soda, borax, mica, sulphate of magnesia, and topaz, the inclination of the resultant axes is greater for the red rays than for the violet ones, while in sulphate of soda, sulphate of barytes, nitre, arragonite, sugar, and hypo-sulphite of strontian, the inclination of the resultant axes is least for the red rays.

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* We have not seen M. Fresnel's Memoirs, and are not aware that they are published. The preceding notice of them is taken from M. Biot's paper on Rotatory Polarisation.

† *Phil. Trans.* 1820, Part i. p. 45—100.

Mr. Herschel next directs his attention to the curious system of deviated tints, which Dr. Brewster had long before discovered in Apophyllite. The phenomena exhibited by this mineral Mr. Herschel conceives to be entirely independent of the principal cause which produces the deviation in crystals with two axes, and he ascribes them to the circumstance of the mineral exercising nearly the same action upon all the colours of the spectrum, the action being equal on the red and indigo rays, a little greater for the yellow and the green, and a little less for the violet, in consequence of which this mineral forms rings of nearly the same magnitude when exposed to all the homogeneous colours.

In a subsequent Memoir, *On certain remarkable instances of deviation from Newton's scale in the tints developed by crystals with one axis of double refraction*, which was read on the 1st May, 1820, and published in the 1st volume of the Transactions of the Cambridge Philosophical Society, Mr. Herschel has resumed his inquiry into the anomalous actions of Apophyllite. He begins this valuable paper, by showing that all the phenomena described in his former communication support, in a remarkable degree, the theory of rectangular axes maintained by Dr. Brewster; and that the circumstance of the apparent axes having different positions for the differently coloured rays, is hostile to the opinion of Biot, that these are the real axes of the crystals. He then proceeds to show, that the law of proportional action on the differently coloured rays, (viz. that all bodies, in their action on coloured light, follow precisely the order and proportion stated in the table of Newton for the colours of thin plates of air,) assumed by Biot as the groundwork of all his inquiries and theories respecting both the phenomena of the ordinary and the rotatory polarisation, has no foundation whatever in the nature of light. Mr. Herschel then proceeds to describe the several remarkable peculiarities in the action of Apophyllite on polarised light. He confirms the observations of Dr. Brewster, that in some specimens of this remarkable mineral, there is a superposition of laminæ of different polarising powers, and he shows that these laminæ have even a different proportional action on the different colours of the spectrum. He next describes a particular specimen, in which the law of proportional action was so far subverted, that the red rays appeared to be more energetically acted upon than the violet, and to such a degree, that the whole prismatic spectrum was displayed in the first ring; and he shows that the hyposulphite of lime affords another example of deviation from Newton's scale, the action upon the different rays increasing with great rapidity from the red to the violet. In a third memoir, read before the Cambridge Society, on the 7th May, 1821, but not yet published, Mr. Herschel has resumed the subject of these anomalous actions upon light. "Upon reconsidering his results, it appeared that these specimens (viz. of Apophyllite, which produced an inversion of the Newtonian scale) could not be referred exclusively either to the class of attractive or of repulsive doubly refracting crystals, nor to the intermediate class, which is devoid of the property of double refraction. They appeared to belong at once to all the three classes of media just mentioned, possessing the property of attractive crystals, when exposed to the rays forming one extreme of the spectrum, and of repulsive, in their action on the other extreme; while, for certain intermediate rays, they were altogether devoid of the property of double refraction. Mr. Herschel was led to this inference, by observing that the curves whose ordinates represented the polarising energy, after approaching very rapidly to the axis, would again recede rapidly from it on the same side, except the ordinates were supposed to become negative, which appeared more probable. This induced him to examine the truth of his supposition, by measures taken in homogeneous light, and the result was a complete confirmation of the remarkable singularity above noticed."*

The discovery of this curious property, though belonging only to a particular crystal, (for the general action of Apophyllite is positive or attractive for all the rays of the spectrum,) we consider to be of great value, as it affords a decided case of an imperfect equilibrium of action. Instead, therefore, of supposing that a single axis of double refraction is capable of developing two opposite actions upon the extreme rays of the spectrum, and no action at all upon the intermediate ones, Dr. Brewster has shown that these curious anomalies have their origin in the unbalanced action of three rectangular axes,—an opinion which derives great support from the circumstance, that if the primitive form of Apophyllite be made to vary in one dimension, it will pass through that of the cube; and which affords a perfect explanation of all the anomalous tints of Apophyllite.

The attention of Mr. Herschel was early directed to the phenomena of circular or rotatory polarisation, as seen along the axis of quartz; and the account of his experiments, which was read before the Cambridge Philosophical Society on the 17th April, 1820, is printed in the first volume of their Transactions. "Although M. Biot," as Mr. Herschel remarks, "has assured us that no peculiarity in the crystalline form can lead us to conjecture what may prove the direction of rotation in a given specimen of rock crystal previous to trial," yet Mr. Herschel actually found, that the direction of the rotation was invariably the same with that of the Plagiedral planes adjacent to the summit, the polarisation being direct or retrograde, according as these planes leaned forward or backward round the summit. This most important fact has been established by experiments on no fewer than *fifty-three* crystals, in all of which the relation was found without exception. In comparing the number of crystals, in which the Plagiedral planes had an inclination to the left with those which are inclined to the right, Mr. Herschel determined that the former were to the latter nearly as 2 to 1.[*]

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* Proceedings of the *Cambridge Philosophical Society*, in the *Edinburgh Philosophical Journal*, vol. v. p. 213.

Although the Achromatic telescope was invented, and received all its improvements in England, yet the attention of the English mathematicians had never been directed to the mathematical theory of their construction. Mr. Herschel is the first of our countrymen who has investigated this difficult subject; and his paper "*On the aberrations of compound lenses and object glasses*," which was read to the Royal Society on the 22d March, 1821, will, we have no doubt, be held in equal value both by the mathematician and the optical artist. As the problem of the destruction of the spherical aberration in a compound object glass of two or more lenses is indeterminate, it becomes a matter of the greatest importance to fix the best possible condition for limiting it. D'Alembert had proposed the condition of annihilating the spherical aberration of rays *of all colours*, and also the superior one of destroying the aberration for an object situated out of the axis of the telescope; but both of these are as useless in practice as they are over-refined in theory. Clairaut has employed a condition better than either of them, viz. that of the lenses touching throughout the whole extent of their interior surfaces, which has the advantage of giving convenient curvatures; but Clairaut used the refractive indices of 1 600 and 1.55, which belong to glass not easily met with; and when the average values of those kinds of glass, which are likely to occur most frequently, are employed, the construction becomes imaginary for the more dispersive kinds of glass, and within the limits for which it is real, the radii of curvature vary with such rapidity, that it is difficult to interpolate between their calculated values.

The only valuable method of limiting the problem, is that which Mr. Herschel has adopted, and which has been so unaccountably overlooked, although the formulæ of aberration, as he remarks, almost force it upon our notice. The object of this condition is, to insure the destruction of the spherical aberration, not only for rays which are parallel and flow from very remote objects, but also for those which diverge from objects placed at any moderate finite distance, so as to produce a telescope equally perfect for terrestrial and celestial purposes. Although the accomplishment of this object is one of considerable utility, yet Mr. Herschel's condition has other and still higher advantages. The curvatures necessary in his construction are all more moderate than in almost any other proposed on theoretical grounds. The radii of the two exterior surfaces vary within such narrow limits by any variation either in the refractive or dispersive powers, that from this circumstance alone there results the following simple practical rules for calculating the curvatures in any proposed state of the data, viz. "*That a double object glass will be nearly free from aberration, provided the exterior surface, or the radius of the crown lens, be* 6 72, *and of the flint* 14.2, *the focal length of the combination being* 10 00, *and the radii of the interior surfaces being computed from these data by the formulæ given in all elementary works on optics, so as to make the focal lengths of the two glasses in the direct ratio of the dispersive powers.*[†]"

From this brief account of the optical labours of Mr. Herschel, our readers will join us in the anticipation of still greater efforts. Possessing the rare combination of mathematical, chemical, and physical acquirements, in a degree unequalled by any philosopher of the present day, we have no doubt that every branch of science will soon experience the influence of his genius and industry; but while we indulge this agreeable prospect, that the reputation of English science will be sustained by his talent, we are not less gratified with the certainty that its liberal and disinterested character will also be preserved by his own, and that those personal and national jealousies, which, in attempting to establish a monopoly of fame, have perverted the history of optical discoveries, will find in him a determined enemy, and will be finally put down by the disinterested philosophers of all countries.

For farther information on the history of optics, the reader is referred to the following works:

Montucla's *Historie des Mathematiques*, 4 vols. Priestley's *History and Present State of Discoveries relating to Vision, Light, and Colours*, Lond. 1772, 2 vols. Bossut's *Hist. Gen. des Mathematiques*, 2 vols. 8vo. Smith's *Compleat System of Optics*, 2 vols. Camb. 1738. Baptista Porta, *Magia Naturalis*, 1658. Id. *De Refractione*, 1593. Kircher, *Ars Magna Lucis et Umbræ*, 1671. Roger Bacon's *Opus Mojus*. Risner, *Opticæ Thesaurus*, Bas. 1585. De Dominis *de Radiis Visus et Lucis*, Ven. 1611. Borelli, *De Vero Telescopii Inventore*, Hag. 1655. Kepleri *Dioptrica*, Augsb. 1611 Descartes's *Dioptrica*, in his *Opusc.* tom. ii. Huygenii, *Dioptrica*, 1690, and *Traité de la Lumiere*. Vossius, *De Natura Lucis*. Zucchi *Optica Philosophia*, Lyons, 1652. Recorde's *Pathway to Knowledge*, Lond. 1551. L. Digges's *Pantometria*, Lond. 1571 and 1591. *Philosophical Magazine*, vol. xviii. and xix. J. Gregory's *Optica Promota*, 1663. Grimaldi, *Physico-Mathesis de Lumine*, Bolog. 1665. Newton's *Optics*, 1718, and *Lectiones Opticæ*, 1728. Mariotte, *Oeuvres*, 2 vols. Leyd. 1717. Le Cat's *Traité des Sens*, Amst. 1744. Bouguer's *Traité d'Optique*. Lambert's *Photometria*, Augsb. 1760. Porterfield *On the Eye*, 2 vols. Edin. 1759; and Dr. Thomas Young's *Lectures on Natural Philosophy*, 2 vols. Lond. 1807. See also in this work the articles Aberration, Accidental Colours, Achromatic Telescopes, Burning Instruments, Camera Lucida, Kaleidoscope, and Microscope.

In proceeding to give an account of the science of optics, our object is to draw up an article as practical and intelligible as is consistent with the nature of the subject, and to omit all those mathematical discussions which are not necessarily connected with the principles or leading objects of the science. In doing this, we shall *first* treat of the Theory of Optics; *secondly*, the Application of this Theory to the explanation of Natural Phenomena; and *thirdly*, of the Principles and Construction of Optical Instruments.

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[*] See the *Edinburgh Philosophical Journal*, vol. vi. p. 379; and also vol. iv. p. 371. Mr. Herschel's second paper on the deviation of the tints will be found in the same Journal, vol. iv. p. 334, and vol. v. p. 334. *Edin. Trans.* vol. xi. Part ii. p. 317.

[†] The reader will find a very valuable and popular abstract of Mr. Herschel's paper, drawn up by himself, under the title of *Practical Rules for the determination of the radii of a double achromatic object glass*, in the *Edinburgh Philosophical Journal*, vol. vi. p. 361—370.

PART. I. ON THE THEORY OF OPTICS.

THE theory of optics embraces the two great divisions of Geometrical and Physical Optics, and comprehends, 1. DIOPTRICS; 2. CATOPTRICS; 3. CHROMATICS; 4. THE INFLEXION OR DIFFRACTION OF LIGHT; 5. THE PHENOMENA OF THIN AND THICK PLATES; 6. THE SUBJECT OF DOUBLE REFRACTION AND POLARISATION.

Although the nature of light is absolutely unknown, and probably will long remain among the arcana of science, yet philosophers have been led by the phenomena which it exhibits to suggest two hypotheses respecting its origin and propagation. By one party, including Newton, and a great number of English philosophers, light is supposed to consist of material particles emitted by the luminous body with prodigous velocity, moving uniformly in straight lines, and capable of having its qualities and its direction altered by reflexion from the surfaces of bodies, by refraction through their substance, and by inflexion in passing by their edges. By another party, including Descartes, Huygens, and Euler, light is supposed to resemble sound, and to consist in the undulations of a highly elastic fluid, diffused through all nature, and excited by the action of the luminous source.

During the last century, the Newtonian theory of luminous particles was almost universally entertained both in England and on the Continent; but the discoveries of the present day have revived the theory of Huygens, and it seems highly probable that this great question will speedily be set to rest.

But whatever be the origin of *light*, and the mode of its propagation through space, it has certain general properties, which have been discovered by experiment, and are entirly independent of its nature.

1. *Light is emitted in all directions, and from every point in the surface of luminous and visible bodies.*—This property of light is established by the fact, that wherever we are placed in relation to a luminous or visible body, every point of the part of the body turned towards us is visible. When the body is not self-luminous, the light by which it is visible must be that which, coming originally from a self-luminous source, is reflected from the surface and interior parts of the visible body.

2. *Light consists of separate and independent parts.*—A beam or mass of light flowing from a luminous body may be divided laterally into any number of smaller portions, which are called *rays of light*. These rays may be supposed to be divided into smaller portions in the direction of their length; for we can stop light at any point of its path, and suffer the rest of it to proceed on its course. Hence we may with perfect propriety call one of these portions of a ray of light a *particle*, or small portion of light, without considering whether it consists of actual matter, or is merely the undulation of an elastic medium.

3. *Light, whether emitted directly from the sun, or reflected from the planets, moves at the rate of* 195,000 *miles per second.*—This important fact was determined by Roemer, as we have already seen in our history of the science. See page 475.

4. *Light, when moving in the same uniform medium, proceeds in a straight line.*—The form of the shadows of bodies, and the impossibility of seeing objects through bent tubes, however small be their flexure, afford the most simple and palpable proof of this property of light.

5. *When light issues from a luminous point, and passes through a non-resisting and non-absorbing medium, its density at different distances from that point is inversely as the square of the distance.*—If we suppose that the light from the luminous point passes through a rectangular aperture at a given distance from the point, and is received at a greater distance upon a white ground, the luminous image of the rectangular aperture will be a similar rectangle, and the triangles formed by the rays passing by the ends of the homologous sides will be similar. Hence it follows, that the homologous sides will be to one another as their distances from the luminous point; and since the areas are as the squares of the homologous sides, the areas will be as the squares of their distances; but as the densities are inversely as the areas, they will also be inversely as the squares of the distances.

6. *Rays of light do not consist of contiguous particles or portions.*—When rays of light, issuing from different sources, cross one another, they do not seem to disturb each other's motion, or produce indistinct or imperfect vision, which would undoubtedly be the case if they consisted of contiguous portions. If a number of luminous balls were discharged from a cannon with great rapidity, they would appear to occupy an uninterrupted line, though they were actually moving at a considerable distance from one another. This effect, which may be shown more simply by whirling round a burning stick, so as to make it form in the air a complete circle of light, arises from the duration of the impression of light upon the retina. M. d'Arcy has shown, that the impression of light continues eight-thirds, or nearly one-eighth of a second; and as light moves through 26,010 miles during that small portion of time, it is evident that constant vision will be maintained by a succession of luminous particles or luminous waves 26,010 miles distant from each other.

CHAP. I.

ON DIOPTRICS.

The word *Dioptrics*, from the Greek Διὰ, *through*, and οπτομαι, *to see*, is that branch of optics which treats of the *refraction of light*, or of the changes of direction which light experiences in passing *through* transparent bodies.

SECTION I.

On the General Principles of Refraction.

Def. 1. The term *Refraction*, from the Latin *Refractio*, is used to denote the change, similar to breaking or bending, which takes place in a ray of light when it falls from air upon any substance, such as *Water* or *Glass*, or from these substances into air.

Def. 2. A *Medium* is the name given to any portion of space or of matter, which either allows light to pass through it, or reflects it from its surface. Those media which transmit light, are called *refracting* or *transparent*, or *diaphanous media*; and those which either reflect the rays, or absorb them completely, so as to transmit no light, are called *opaque media*. Every medium except a vacuum is a reflecting medium, unless when they are reduced to such minute films, that they cease to have the power of driving back the light which falls upon them.

Def. 3. Light or its rays are said to be *Incident* upon a *Medium*, or upon a body, when they fall upon that medium or body.

Prop. I.

When a ray of light falls from a rarer upon a denser refracting medium, it suffers such a change in its direction, that the sine of the angle of incidence is to the sine of the angle of refraction in a constant ratio, and the incident and the refracted ray are in the same plane.

Let AC, Plate CCCCXXVIII. Fig. 1. be a ray of light incident on the surface RS of water, or any other medium. This ray is found to suffer such a change in its direction, that instead of proceeding in a line which is a prolongation of AC, it is bent or refracted at C into the direction CE. In like manner, another ray aC, incident on the same point C, is found to be bent or refracted into the line Ce. Through the point C draw the line PCQ perpendicular to the refracting surface RS, and upon C as a centre describe a circle ABEa, then the angle ACP is called *the Angle of Incidence ;* AC ECQ *the Angle of Refraction*, for the ray AC; while aCP is the angle of incidence, and eCQ the angle of refraction of the ray aC. If we now compare the angles of refraction with their corresponding angles of incidence, we shall find no particular relation between them ; excepting that the one increases with the other, and *vice versa ;* but if we compare the Sines of these angles, viz. AD, the Sine of the angle of incidence ACP with EF, the Sine of the angle of refraction ECQ, and also $a\,d$ with $e\,f$, we shall find that the ratio of the one to the other is constant, whatever be the value of the angles of incidence or refraction.

If the surface RS is that of *Water*, AD will be to EF, or $a\,d$ to $e\,f$, as 4 to 3 nearly.

If the surface RS is that of *Crown glass*, AD will be to EF, and $a\,d$ to $e\,f$, as 3 to 2.

If the surface RS is that of *Zircon* or *Sulphur*, AD will be to EF, and $a\,d$ to $e\,f$, as 2 to 1, or 1 to $\frac{1}{2}$.

If the surface RS is that of *Diamond*, AD will be to EF, and $a\,d$ to $e\,f$, as 1 to $\frac{2}{5}$. Hence it follows, that *the Sine of the angle of Incidence is to the Sine of the angle of Refraction in a constant ratio.*

By admitting the light through a small aperture at A, so as to pass through another aperture at C, and fall upon the bottom of the vessel at E, it will be found that the three points A, C, E, are always in the same straight line, whatever be the angle of incidence ACP. Hence it follows, that the refracted ray CE, and the incident ray AC, are always in the same plane.

Cor. When a ray passes from a rarer into a denser medium, the refraction is always made *towards the perpendicular.* This follows from the angle of refraction always being less than the angle of incidence.

Supposing the sine of the angle of refraction to be always 1, then the sine of the angle of incidence will be nearly 1.33 in water, and 1.50 nearly in glass. In this case the sine of the angle of incidence, or 1.33 and 1.50, is called the *Index of Refraction*, or the *Co-efficient of Refraction ;* and this mode of expression is universally adopted to indicate the relation between the sines of incidence and refraction. When we are told, for example, that the refractive power, or the Index of refraction belonging to diamond, is about 2.5, we learn, that if 2.5 is to represent the sine of the angle of incidence, the sine of the angle of refraction will be 1.

Prop. II.

When a ray of light falls from a denser upon a rarer medium, as in passing from water to air, it will suffer such a change in its direction, that the sines of the angles of incidence and refraction will be in a constant ratio.

Let EC, Fig. 1. be a ray which is incident at C, on the rarer medium above RS, then if EC be the refracted ray, when AC is the incident ray from the rarer medium, it is found that AC is the refracted ray when EC is the incident ray.

This is obvious, from the simple experiment mentioned under the last proposition; for since the points A, C, B, are seen in a straight line, it follows that the rays of the object at E reach the eye along the line CA. Hence it follows, that the sines of the angles of incidence and refraction are in the same ratio as when AC was the incident ray; that is, in a constant ratio.

When the refraction is made from water into air, this ratio is 4 to 3, or as 1.33 to 1, and so on with other bodies.

Cor. When a ray passes from a denser into a rarer medium, the refraction is always made *from the perpendicular.*

The general truth of this corollary is well shown by the common experiment known since the time of Ptolemy, of rendering a shilling at the bottom of a vessel visible by refraction. If we place a shilling at the point E, Fig. 1. and suppose CQES to be the opaque sides of a vessel, then it is clear that the eye placed at A will not see the shilling at E, if there is no water in the vessel CQES. The moment, however, that it is filled with water, the ray EC, issuing from the shilling, will be bent from the perpendicular CP, in the direction CA, so as to reach the eye of the observer at A.

Prop. III.

If a ray of light is incident from a denser upon a rarer medium, it is not capable of being refracted, but will return into the rarer medium, when the angle of incidence is greater than that at which the Sine of the angle of refraction becomes equal to the Radius.

Let AC, Fig. 2. be the ray incident upon the rarer medium RS. It will be refracted from the perpendicular DF into the direction CE, so that AD is to EF in a constant ratio. If we increase the angle ACD, the angle FCE will also increase till the lines CE and FE coincide with the radius CS. But if beyond this position of the ray AC, the angle ACD is still farther increased, it is manifest that its Sine is also increased ; and, consequently, in order that the ratio may be constant, the Sine of refraction EF must also increase, which is impossible, as it is already by hypothesis equal to the radius CS. Hence it follows, that whenever the angle of incidence is greater than that at which the Sine of the angle of refraction becomes equal to the radius, the ray cannot be refracted consistently with the constant ratio of the sines.

This is found to be the case by experiment; and at the angle thus indicated, all the incident rays are reflected from the inner surface of the denser medium, having a reflexion more brilliant than what can be produced from any metallic surface. The reflexion is then called *Total Reflexion.*

The angle at which total reflexion takes place may be thus found: Let x be the sine of incidence at which the corresponding sine of refraction is 1, and let m represent the index of refraction, or the ratio of the sines; then $x : 1 = 1 : m$ by Prop. I. and $x = \frac{m}{1}$, that is, total reflexion takes place when the sine of incidence is equal to the reciprocal of the index of refraction.

In *Water*, whose index of refraction is 1 336, the angle of total reflexion is 48° 28′

In *Glass*, whose index of refraction is 1.50, it is 41° 49′.

In *Zircon* and *Sulphur*, whose index of refraction is about 2.00, it is 30° 0′.

In *Diamond*, whose index of refraction is about 2.50, it is 23° 35′.

PROP. IV.

If m and m' are the indices of refraction from a vacuum into any two media of different refractive powers, the index of refraction for a ray of light passing out of the first or the rarest, into the second or the densest, will be $\frac{m'}{m}$.

Let a ray of light be incident from air upon a parallel plate of water, whose index of refraction is m, lying upon a parallel plate of glass, whose index is m', then it is manifest that the angle of incidence from the water upon the glass, is the angle of refraction from the air into the water, and consequently their sines are to the sine of incidence as $1 : m$. In like manner, the angle of refraction from the water into the glass, is the angle of incidence from the glass into the air, and consequently its sine is to that of the angle of refraction, from glass into air, as $1 : m'$. Hence the sinee of incidence from water to glass is to the sine of refraction, as $m' : m$, or to make one of these unity, we have $m : m' = 1 : \frac{m'}{m}$.

In *Water* and *Glass*, when m and m' are 1.525 and 1.336, the index of refraction is $\frac{m'}{m} = 1.141$.

From the principles explained in the preceding propositions, the refractive powers of bodies, or their indices of refraction, may be easily obtained. The method used by Ptolemy, and described in page 591, is sufficiently simple; and after we have measured one angle of incidence, and one angle of refraction, we have only to divide the sine of the former by the sine of the latter, in order to obtain the index of refraction. This method, however, is never used, as a much more correct result may be obtained when the refraction is increased by the action of two surfaces, as we shall afterwards have occasion to describe. (See Prop. IX. p. 634.)

In the meantime, we shall collect into one table the principal observations on refractive powers that have hitherto been made. Many of these observations are very accurate; but others, especially those on doubly refracting crystals, are less correct, in consequence of their having been made before the laws of double refraction for crystals with two axes had been determined.

It may be proper to state, that all the observations made by Dr. Wollaston are, according to Dr. Young, appropriate to the extreme red rays, whereas those made by Dr. Brewster belong, in the case of fluids and soft substances, to the most luminous rays of the spectrum, and in minerals to the mean refrangible rays of the spectrum. The object of these last experiments was not to obtain measures of refractive powers for optical purposes, or for ascertaining the phenomena of double refraction, but solely to determine the general action of various bodies upon light. The accuracy of the numbers, therefore, depends entirely upon the nature of the specimens which were used, and which were often of the worst description.

*Table of Refractive Powers.**

	Index of Refraction.	Observers.
Chromate of Lead, gr. refr.	2.974	Brewster.
Do. do. another kind	2.926	
Red Silver Ore	2.564	
Realgar, artificial	2.549	
Chromate of Lead, least refr.	2.500	
Octohedrite	2.500	
Diamond	2.755	Rochon.
Do.	2.487	
Do.	2.470	
Do.	2 439	Newton.
Blende	2.260	
Phosphorus	2.224	
Glass of Antimony	2 216	
Do.	1.980	Wollaston.
Sulphur melted	2.148	
Do Native	2.115	
Do.	2.04	Wollaston.
Do.	1.958	Hauy.
Scaly Oxide of Iron	2.1	Young.
Glass made of Lead, 3. Flint 1.	2 028	Zeiher.
Tungstate of Lime, greatest	2.129	
least	1.970	
Carbonate of Lead, greatest	2 084	
least	1 813	
Calomel	1.970	
Zircon, greatest ext.	2.015	
least ext.	1.961	
Do.	1 95	Wollaston.
Glass made of Lead, 2. Sand 1.	1.987	Wollaston.
Sulphate of Lead	1 925	
Glass of Antimony	1.889	Newton.
Glass, Lead 2. Flint 1.	1.830	Zeiher.
Garnet	1.815	
Spinelle Ruby	1 812	Wollaston.
Arsenic	1 811	Wollaston.
Blue Sapphire	1.794	
White do.	1.768	Wollaston.

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* All the observations without a name were made by Dr. Brewster.

	Index of Refraction.	Observers.
Pyrope	1.792	
Nitrate of Silver, greatest	1.788	
least	1.729	
Glass, Lead 1. Flint 1.	1.787	Zeiher.
Ruby	1.779	
Feldspar	1.764	
Chrysoberyl	1.760	
Nitrate of Lead	1.758	
Glass, Lead, 3. Flint 4.	1.732	
Glass, Lead 1. Flint 2.	1.724	
Axinite	1.735	
Deep Red Coloured Glass	1.729	
Glass tinged red by Gold	1.715	
Epidote, greatest	1.703	
least	1.661	
Carbonate of Strontites, greatest	1.700	
least	1.543	
Boracite	1.701	
Orange Coloured Glass	1.695	
Sulphuret of Carbon	1.678	
Chrysolite, greatest	1.685	
least	1.660	
Arragonite, ordinary	1.6931	Malus.
extraord.	1.5348	Malus.
Calcareous Spar, ordinary	1.6543	Malus.
extraord.	1.4833	Malus.
Sulphate of Barytes	1.6468	Malus.
extraord.	1.6352	Malus.
ordin.	1.6201	Biot.
Topaz, colourless	1.6102	Biot.
Brazilian Topaz, extraord.	1.6401	Biot.
ordin.	1.6325	Biot.
Anhydrite, extraord.	1.6219	Biot.
ordin.	1.5772	Biot.
Euclase, extraord.	1.6630	Biot.
ordin.	1.6429	Biot.
Mother-of-Pearl	1.653	
Glass, Hyacinth, red	1.647	
Oil of Cassia	1.641	
Opal Coloured Glass	1.635	
Balsam of Tolu	1.628	
Castor	1.626	
Muriate of Ammonia	1.625	
Guiacum	1.619	
Flint Glass	1.616	
Another kind	1.604	
Meionite	1.606	
Flint Glass	1.60512	Malus.
Do.	1.576	
Another kind	1.596	
Flint Glass, different kinds	1.625	Boscovich.
	1.604	
	1.594	
	1.593	
	1.590	
Essential Oil of Bitter Almonds	1.603	
Green Coloured Glass	1.615	
Purple Coloured Glass	1.608	
Oil of Anise Seeds	1.601	
Balsam of Peru	1.597	
Gum Ammoniac	1.592	
Tortoise Shell	1.591	
Pitch	1.586	
Balsam of Styrax	1.584	
Bottle Glass	1.582	
Tartaric Acid	1.575	
Tartaric Acid	1.518	
Pink Coloured Glass	1.570	
Horn	1.565	
Quartz, extraord.	1.5582	Malus.
ordin.	1.5484	Malus.
Mellite	1.556	
Do.	1.538	
Gum Mastic	1.560	
Burgundy Pitch	1.560	
Rosin	1.559	
Turpentine	1.557	
Rock Salt	1.557	
Sugar after being melted	1.554	
Gum Thus	1.554	
Comptonite	1.553	
Chalcedony	1.553	
Sulphate of Copper greatest	1.552	
least	1.531	
Copal	1.549	
Canada Balsam	1.549	
Elemi	1.547	
Oil of Tobacco	1.547	
Plate Glass	1.542	Boscovich.
Do.	1.538	
Do.	1.529	
Do.	1.526	
Do.	1.514	
Old Plate Glass	1.545	
Dichroite	1.544	
Glass of St. Gobin	1.543	Wollaston.
Colophony	1.543	Wollaston.
Bees' Wax	1.542	Wollaston.
Olibanum	1.544	
Phosphoric Acid, solid	1.544	
Carbonate of Barytes, least	1.540	
Crown Glass	1.534	
Caoutchouc	1.534	
Do.	1.524	Wollaston.
Radcliffe Crown Glass	1.533	Wollaston.
Glass of Borax	1.532	
Glass of Phosphorus	1.532	
Oil of Sassafras	1.532	
Do.	1.536	Wollaston.
Do.	1.544	Euler.
Oil of Cloves	1.535	Wollaston.
Centre of the Crystalline of a Fish	1.530	Wollaston.
Dry Crystalline of an Ox	1.530	Wollaston.
Glass like Cinnamonstone	1.580	
Balsam of Capivi	1.528	
Leucite	1.527	
Plate Glass	1.527	
Citric Acid	1.527	
Shell Lac	1.525	
Crown Glass, common	1.525	Wollaston.
Sulphate of Lime	1.525	Wollaston.
Gum Myrrh	1.524	
Borax Glass, 1. Borax, 2. Silex	1.522	
Gum Dragon (Tragacanth)	1.520	
Mesotype, greatest	1.522	
least	1.516	
Nitre, greatest refr.	1.5145	
least	1.335	
Do.	1.5238	Newton.
Tartrate of Potash and Soda	1.515	
Dutch Plate Glass	1.517	
Sulphate of Zinc, ord.	1.517	

	Index of Refraction.	Observers.
Nadelstein Faroe	1.5153	
Bees' Wax, Reaum. 14°	1.5123	Malus.
Do. melting	1.4502	Malus.
Do. at boiling point	1.4416	Malus.
Gum Arabic	1.512	
Sulphate of Potash	1.509	
Do.	1.495	Wollaston.
Oil of Cumin	1.508	
Stilbite	1.508	
Nut Oil	1.507	
Oil of Pimento	1.507	
Oil of Sweet Fennel Seeds	1.506	
Oil of Amber	1.505	Wollaston.
Oil of Rhodium	1.500	
Oil of Beech Nut	1.500	
Oil of Nutmeg	1.497	Wollaston.
Balsam of Sulphur	1.497	
Sulphate of Iron, greatest	1.494	
Oil of Angelica	1.493	
Oil of Marjoram	1.491	
Oil of Caraway Seeds	1.491	
Castor Oil	1.490	
Obsidian	1.488	
Tallow, cold	1.49	Wollaston.
Sulphate of Magnesia	4.488	
Do.	1.465	
Oil of Hyssop	1.487	
Camphor	1.487	Wollaston.
Oil of Feugreck	1.487	
Cajeput Oil	1.483	
Oil of Almonds	1.483	
Oil of Savine	1.482	
Oil of Penny Royal	1.482	
Sulphate of Ammonia and Magnesia	1.483	
Carbonate of Potash	1.482	
Oil of Lemon	1.379	
Oil of Spearmint	1.481	
Butter, cold	1.480	Wollaston.
Opal, partly Hydrophanous	1.479	
Oil of Thyme	1.477	
Oil of Dill Seed	1.477	
Essence of Lemon	1.476	Wollaston.
Oil of Turpentine	1.475	
Do. common	1.476	Wollaston.
Do. rectified	1.470	Wollaston.
Rape Seed Oil	1.475	
Borax	1.475	
Oil of Juniper	1.473	
Oil of Beech	1.471	
Oil of Bergamot	1.471	
Oil of Olives	1.470	
Spermaceti Oil	1.470	
Oil of Rosemary	1.469	
Oil of Olives,	1.467	Newton.
Do.	1.469	Wollaston.
Oil of Lavender	1.467	Wollaston.
Tallow melted	1.464	Wollaston.
Oil of Poppy	1.463	
Oil of Lavender	1.457	
Alum	1.457	Wollaston.
Oil of Chamomyle	1.457	
Oil of Wormwood	1.453	
Crystalline Lens of an Ox	1.463	Euler.
Do.	1.447	Wollaston.
Spermaceti melted	1.446	Wollaston.
Hydrophosphoric Acid	1.442	
Sulphuric Acid	1.440	
Sulphuric Acid	1.435	Wollaston.
Do.	1.4285	Newton.
Fluor Spar	1.436	
Do.	1.433	Wollaston.
Oil of Rhue	1.433	
Phosphoric Acid, fluid	1.426	
Nitric Acid, Spec. Grav. 1.48	1.410	Wollaston
Muriatic Acid highly concentrated	1.4098	Biot.
Do. strong	1.401	
Nitric Acid	1.406	
Nitrous Acid	1.396	
Acetic Acid	1.396	
Malic Acid	1.395	
Alcohol	1.374	
Do.	1.37	Wollaston.
Oil of Ambergrease	1.368	
White of an Egg	1.361	
Do.	1.351	Euler.
Albumen	1.36	Wollaston.
Ether	1.358	Wollaston.
Jelly Fish (*Medusa Æquorea*)	1.345	
Cryolite	1.349	
Distilled Vinegar,	1.314	Euler.
Salt Water	1.343	
Eye, Aqueous Humour	1.3366	
Vitreous Humour	1.3394	
Outer Coat of Crystalline	1.3767	
Middle do.	1.3786	
Central do.	1.3990	
Whole Crystalline	1.3839	
Water	1.336	
Ice	1.310	Wollaston.
Do.	1.307	
Tabasheer	1.11145	
Air, barometer 29.6 thermometer 50°	1.000276	Bradley.
Vacuum	1.000000	

In order to convey to the reader an idea of the different degrees of refraction produced upon a ray of light when acted upon by different bodies, we have given a representation in Fig 3 of the difference of the effects of *Air*, *Tabasheer*, *Water*, *Flint Glass*, *Diamond*, and *Chromate of Lead*, upon the same incident ray AB; CD being supposed to be the refracting surface of each of these substances.

In the preceding Table the refractive powers of different bodies are given, without any consideration of their densities or specific gravities; but it is evident, that if a body of small specific gravity has the same refractive power as another body of greater specific gravity, the former must have a greater absolute action upon light than the latter. Hence, if we wish to measure the absolute refractive powers of bodies, we must take their specific gravities into account.

Sir Isaac Newton has shown, that the refractive power is proportional to the square of the cosine of the angle of refraction when it is a maximum; so that if we call R the absolute refractive power, m the index of refraction, and S′ the specific gravity, we shall have $R = \frac{m^2-1}{S}$, from which the absolute refractive powers of bodies may be calculated, when their specific gravities and their indices of refraction are known. In this way we have calculated the following Table, comprehending bodies of all varieties of refractive power, from *Air* up to *Chromate of Lead.*

Table showing the absolute Refractive Powers of several Bodies.

	Index of Refraction.	Observers.
Tabasheer . . .	976.1	
Cryolite	2742	
Fluor Spar . . .	3426	
Sulphate of Barytes . .	3829	
Air	4530	Biot.
Quartz	5414.57	Malus.
Sulphuric Acid . .	6124	Newton.
Calcareous Spar . .	6423.5	Malus.
Rock Crystal . .	6536	
Nitric Acid . . .	6676	
Flint Glass, lowest . .	7238	
Ruby	7388 8	
Brazilian Topaz . .	7586 7	
Water	7845.7	Malus.
Flint Glass, highest . .	8735	
Spirit of Wine rectified .	10121	Newton.
Carbonate of Potash . .	10227	
Chromate of Lead . .	10436	
Muriate of Ammonia .	11290	
Nitre	11962	
Muriate of Soda . .	12086	
Camphor . . .	12551	Newton.
Oil of Olives . .	12607	Newton.
Lintseed Oil . . .	12819	Newton.
Bees' Wax . . .	13308 1	Malus.
Spirit of Turpentine . .	13222	Newton.
Amber . . .	13654	Newton.
Octohedrite . . .	13816	
Diamond . . .	13964.5	Malus.
Do.	14556	Newton.
Realgar, artificial . .	16666	
Ambergris . . .	17000	
Sulphur . . .	22000	
Phosphorus . . .	28857	
Hydrogen . . .	29964	
Do.	31862	

In addition to the conclusions which Newton drew from his measures of the absolute refractive powers of bodies, and which we have given in p. 606 of the History of Optics, the preceding Table presents us with others of equal interest. With the exception of *Tabasheer*, the substances that contain fluoric acid, such as *Cryolite* and *Fluor Spar*, have lower absolute refractive powers than any other bodies.

When the substances become inflammable, their absolute refractive powers increase very rapidly. *Diamond*, *Sulphur*, *Phosphorus*, and *Hydrogen*, have all refractive powers increasing with their inflammability; and such is the rapidity with which these powers augment, that the absolute number for *Hydrogen* is more than *ten* times that for *Cryolite*. The high absolute refractive power of *Ambergris* is very remarkable.

Sect. II. *On the Refraction of Rays by Bodies with Plane Surfaces.*

Prop. V.

When a ray of light is transmitted through a medium bounded by parallel surfaces, the emergent ray will be parallel to the incident ray.

Let AB *b a*, Fig. 4, be the medium, bounded by parallel surfaces AB, *a b* C; and let DE be the incident ray refracted in the direction EF, and emerging in the direction FG; the ray FG will be parallel to DE. Through the points E, F, draw the perpendiculars PQ, RS. Then since PQ and RS are parallel, the angle of refraction QEF at the first surface, is equal to EFR, the angle of incidence at the second surface; but as the ratio of the sine of QEF to DEP is the same as that of EFR to SFG, by Prop. II. the angles DEP and SFG must be equal, and consequently their complements AED, *b* FG; and if we add to these the equal angles AEF, *b* FE, the whole angles DEF, GFE, will be equal, and consequently the rays DE, FG parallel.

Def. A *Prism* in optics is a transparent solid, having at least two plane surfaces inclined to one another.*

Prop. VI.

If the angles of incidence and refraction of a ray transmitted through a prism are so small, that they may be considered as proportional to their sines, the *angle of deviation*, or that which is formed by the incident and emergent ray, will be to the refracting angle of the prism, or the inclination of its faces, as the difference of the sines of incidence and refraction is to the sine of incidence, and the angle of deviation will be invariable in all positions of the ray.

Let I, Figs. 5, 6, 7, be the refracting angle of the prism, QA the incident ray, AC the refracted ray, and CS the emergent ray. Continue the incident and emergent rays to R and T, and at the points of incidence and emergence A and C draw the perpendiculars AB, CD, meeting at E. Calling m and 1 the sines of incidence and refraction, and supposing the ray AC to go out of the prism both ways, we have, by the hypothesis, ACD the angle of incidence to DCT the angle of refraction as m to 1; consequently, Geometry, Prop. VI. ACD : DCT—ACD, or ACT$=m:m-1$, and from the same reasoning CAB : CAR$=m:m-s$, the ray being supposed to go backward along CA. Hence ACD : ACT$=$CAB : CAR, and Eucl. 12.5 ACD + CAB : ACT + CAR $=m:m-1$; that is, AED or AIC : RFS the whole deviation, as $m:m-s$.

Cor. 1. When the ray AC within the prism is coincident with one of the perpendiculars, as AB, Fig. 7, the refraction at B will vanish, and the whole deviation RFS will be produced by a single refraction, and will be the same as when it was produced by the two refractions, as the angle of deviation is invariable.

Cor. 2. If the angle of deviation RFS is given, and also the angle AIC of the prism, the index of refraction may be determined in prisms with small refracting angles.

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[*] It is by no means necessary to the idea of an optical prism, that it is a geometrical solid bounded by three rectangular parallelograms, or even that its planes meet. The inclination of two plane surfaces is the only thing that is essential to an optical prism.

LEMMA.

Let three rays, b I, c I, d I, Fig. 8. be refracted at the surface IK, in passing out of a dense into a rare medium, then if the differences of their incidences b I c, c I d are equal, the sum of the angles of refraction for the extreme rays is more than double of the angle of refraction for the middle ray, that is, AIB + AID $>$ 2AIC.

Round I as a centre describe any circle $a$GAK$a$, cutting the incident rays in the points, b, c, d, and the refracted ones prolonged in B, C, D. Then, since the angle b I c = c I d, we shall have the arch $b\,c = c\,d$. Draw the lines $b\,n$, $c\,o$, $d\,p$, and BN, CO, DP. When arches are small, they are proportional to their sines, and the increase of the arches to the increase of their sines; and when the arches increase, the increase has a greater ratio to the increase of the sine; the ratio always increasing as the arches become larger. Hence the sines of incidence and refraction have a constant ratio, and also their increments; and since A B $>$ $a\,b$, then we have

$$\frac{d\,c}{\text{inc. of } o\,c} > \frac{b\,c}{\text{inc. } n\,b}, \text{ or } \frac{d\,c}{\text{inc. } n\,b},$$

and inc. $n\,b >$ inc. $o\,c$. In like manner,

$$\frac{\text{DC}}{\text{inc. OC}} \text{ is much greater than } \frac{\text{BC}}{\text{inc. } n\,b},$$

and inc. $n\,b \times$ DC much greater than inc. $o\,c$ + BC; and dividing by inc. $n\,b$, and inc. $o\,g$, which have not such a great ratio, we have DC $>$ BC, consequently the sum of the arches AB, AD, is greater than twice AC, that is, AIB + AID $>$ 2AIC.

PROP. VII.

When a ray of light is refracted through a prism, the angle of deviation, or the inclination of the incident and emergent rays, is least when the angles of refraction at both the surfaces of the prism are equal.

Let ACB, Fig. 9, be a prism, and GRSN a ray refracted equally at R and S; and IPQL another ray, unequally refracted, being refracted more at P and less at Q. Let these rays be produced till they meet QL produced in T, and NS produced in V. The angle RVS will be greater than PTQ, and the complement of RVS which is the real angle of deviation, less than that of PTQ. In order to understand this, conceive the rays PQ and RS emerging on both sides from the prism, and thus refracted from a denser into a rarer medium. Now, in the triangles CPQ, CRS, since the angle C is common, the sum of the other angles will be equal; and, therefore, since CRS is an isosceles triangle, 2CRS = CPQ + CQP. Wherefore the incidence of the ray QP at P is as much greater than the incidence of RS at S, as the same incidence is greater than PQ at Q; consequently the differences of the three incidences are equal; and hence, by the preceding lemma, the sine of the angles of refraction, produced by the greatest and least angles of incidence, will be greater than twice the angle of refraction produced at the middle angle of incidence, that is, QPT + PQT $>$ 2RSV, or $>$ RSV + VRS. Since, therefore, in the triangles PTQ, RVS, the sum of the angles at the base PQ is greater than the sum of those at the base RS, the vertical angle RVS is greater than the vertical angle PTQ. But the complements of these two angles are the real angles of deviation produced by the prism, and, consequently, the angle of deviation RVF is less than the angle of deviation PTE.

COR. When the rays are incident, as stated in the proposition, the angle of refraction is equal to half the angle of the prism.

PROP. VIII.

When a ray of light is either incident upon, or emerges perpendicularly from one of the sides of a prism, the sine of incidence will be to the sine of refraction, as the sine of the sum of the angle of the prism and the angle of deviation is to the sine of the angle of the prism.

Let SC, Fig. 7. be a ray incident on the prism AIC, and refracted in the direction CA, so as to emerge at A in a direction AQ perpendicular to IA. The angle of incidence, or TCD is = DCA + TCA, that is, $\angle$ incidence = $\angle$ refraction + $\angle$ deviation; and since $m : 1$ = Sin. $\angle$ incid. : Sin. $\angle$ refract. we have by substitution $m : 1$ = Sin. ($\angle$ Refract. + $\angle$ Deviation) : Sin. $\angle$ Refraction. But in the similar right angled triangles AIC, ADC, the angle DCA = AIC, that is, the angle of refraction is equal to the angle of the prism. Consequently, by substituting the latter in place of the former, we have $m : 1$ = Sin ($\angle$ Prism + $\angle$ Deviation) : Sin. angle of prism. Since SC is the refracted ray, when QA is the incident one, the very same reasoning applies to the case when the ray is incident perpendicularly upon the prism.

COR. Since $m : 1$ = Sin. ($\angle$ Prism + $\angle$ Dev.) : Sin. $\angle$ Prism, we have the index of refraction, or m =

$$\text{Sin. } \frac{(\angle \text{ Prism} + \angle \text{ Dev.})}{\text{Sin. } \angle \text{ Prism}}, \text{ or } m = \frac{\text{Sin. } a + d,}{\text{Sin. } a}$$

calling a the angle of the prism, and d the deviation produced by refraction.

PROP. IX.

When a ray of light is refracted by a prism, so that the angles of refraction at both the surfaces of the prism are equal, the sine of incidence will be to the sine of refraction as the sine of half the sum of the angle of the prism and the angle of deviation, is to the sine of half the angle of the prism.

The circumstances described in this proposition, and represented in Fig. 5. may be reduced to those in Prop VIII. and shown in Fig. 7. by drawing the line IM, Fig. 5 so as to bisect the angle AIC of the prism. For, since IAC = ICA by the hypothesis, and AIM = CIM by construction, the ray AC will be perpendicular to IM. We may therefore consider half the angle of refraction, and consequently half the angle of deviation, as produced by the prism AIM, and the other half by the prism CIM. Hence, for each half of the prism we have $m : 1$ = Sin. (AIM + CAR); Sin. AIM, that is,
$m : 1 = \text{Sin. } \frac{(\text{AIC} + \text{RFS})}{2} : \text{Sin. } \frac{\text{AIC}}{2}$; or calling a the angle of the prism, and d the deviation, as before, we have

$$m : 1 = \text{Sin. } \frac{a+d}{2} : \text{Sin. } \frac{a}{2} \text{ and}$$

$$m = \text{Sin. } \frac{a+d}{2} \div \text{Sin. } \frac{a}{2}$$

SCHOLIUM.

The two preceding propositions furnish us with excellent practical methods of measuring the refractive powers of solid and fluid bodies, when they are shaped into the form of a prism, and one of these methods possesses the advantage of deducing the index of refraction from a large angle of deviation, or one produced by two separate refractions.

First method.—In the first method, founded on Prop. VIII. a ray of light QA, Fig. 7. is made to fall perpendicularly upon one of the faces of the prism, whose refractive power is required; the angular deviation of this ray is measured either by a divided instrument, or by deducing it from a measurement of its tangent at a given distance from the prism; and when the angle of the prism has been measured by a reflecting goniometer, the value of m, or the index of refraction, is immediately deduced from the formula of Prop. VIII.

In this method, however, we have to encounter the practical difficulty of placing the surface IA perpendicular to the incident ray QA. This may be done pretty nearly, by observing when the reflected ray from the surface nearly coincides with the incident ray, and by various other methods; but as this operation is unnecessary in the second method, and as the first has no peculiar advantages, it is needless to pursue it any farther.

Second method.—The second method is founded on Prop. IX. and derives its practical advantages from the truth in Prop. VII. that the angle of deviation is a *minimum* under the circumstances of Prop. IX. Having placed the prism on the goniometer, as described in our articles CRYSTALLOGRAPHY, and GONIOMETER, let the angle of its two plane or refracting surfaces, be determined with the greatest care, and in the same manner as the angles of crystals are measured, by observing the reflexion of a small luminous image, such as a candle, or an aperture in the window-shutter of a dark room, from both the surfaces. Let the goniometer be now turned round, till the refracted image T of the luminous object at Q is seen through it, and while the eye looks at this image T, let the goniometer be still turned till the image appears stationary, or is at that point where it is nearest Q, or where its deviation is a *minimum*. When this happens, the refracted ray AC, Fig. 5. makes equal angles with the faces IA, IC, by Prop. VII. and therefore the prism is placed in the circumstances of Prop. IX. The point on the wall or the floor, where the most luminous part of the image T is projected, is now to be marked, and the angle of deviation QFT ascertained. This may be done in two ways. By measuring the distances FQ and QT, we shall have $\text{Tang. QFT} = \frac{\text{QT}}{\text{QF}}$; or if QT is not at right angles to QF, QFT may be obtained by measuring the three sides QT, QF, and TF, and deducing the angle from them trigonometrically. The angle QFT may also be measured optically with the goniometer, by bringing the reflected image of Q to coincide successively with the points T and Q; and twice the arch upon the goniometer, corresponding to the revolution of this image from Q to T, will be the angle QFT.

The angle of deviation and that of the prism being thus measured, the index of refraction will be obtained, as in the following example.

Required the index of refraction for *Tabasheer*, the angle of the prism being 22° 9′, and the angle of deviation 2° 30′ 20″.

d = angle of deviation	2° 30′ 20″	
a = angle of prism	22 9	
$a+d$ = sum of these angles	24° 39′ 20″	
$\frac{a+d}{2} = \frac{1}{2}$ sum of these angles	12 19 40	Log. Sin. 9.3294058
$\frac{1}{2} = \frac{1}{2}$ angle of prism	11 4 30	Log. Sin. 9.2835137
$m = \text{Sin.}\ \frac{a+d}{2} \div \frac{a}{2} = 1.11145$		Log. Sin. 0.0458921

Hence the Index of Refraction for *Tabasheer* is 1.11145.

PROP. X.

When a ray of light falls perpendicularly upon the first of two prisms of different refractive powers, to find the angle of deviation produced by their joint actions, when their angles and refractive powers are known, and to determine the refractive power of the first prism from the refractive power of the second.

Let ABC, ACL, Fig. 10, be the refractive angles of two prisms placed in an inverted order, and having a common face AC. The ray DE falling perpendicularly upon AB will pass unrefracted to the point F, in the common face AC, where it will be refracted from the perpendicular in the direction FOK; but on arriving at the point O in the side LC, it will be refracted from the perpendicular in the direction OR. Let H be the point of intersection of the perpendiculars IF, PO, drawn through the points F, O, and S, Q, the intersections of the straight lines OH, OR, with DG, the prolongation of the incident ray DE. Now POR = OQS + OSQ, but OQS = GQR, the total refraction of the emergent ray OQR from its primitive direction DG; and since in the quadrilateral figure BESO, BES, BOS, are right angles, the angle ABC must be the supplement of ESO to two right angles, and must therefore be equal to OSQ. But because ACL = BAC + ABC, ABC is the difference of the refracting angles BAC and ACL of the two prisms. If, therefore, we call the angle BAC $=a$, and ACL $=b$, the last angle of refraction POR $=y$, and the total deviation GQR or OSQ $=d$, we shall have $y = b - a + d$.

On account of the similar right angled triangles AEF, IEF, the first angle of incidence DFI = EAF $=a$, then calling the first angle of refraction HFO $=x$, and making m the index of refraction for the first prism, and m' that of the second, we shall have $m' : m = \text{Sin. } a : \text{Sin. } x$; and $\text{Sin. } x = \frac{m \text{ Sin. } a}{m'} = \frac{m}{m'} \text{ Sin. } a$.

In the quadrilateral figure FHOC, right angled at F and O, the angle FCO is the supplement of FHO; but in the triangle OFH the sum of the two angles OFH, HOF, is the supplement of the same angle FHO; hence ACL=OFH+HOF, and HOF=ACL — OFH; that is, the second angle of incidence is equal to the difference between the angle of the second prism and the first angle of refraction; or $= b - x$, calling the second angle of refraction POR$=y$, we have $1 : m' = \text{Sin. } (b - x) : \text{Sin. } y$; and $\text{Sin. } y = m' \text{ Sin. } (b - x)$.

If we now suppose that the second prism ACL corrects the refraction of the first prism BAC, the deviation d vanishes, or $d = 0$. Hence the formula $y = b - a + d$ becomes $y = b - a$, and by substituting this value of y in the third formula, or $\text{Sin. } y = m' \text{ Sin. } (b - x)$, it becomes $\text{Sin.} (b - a) = m' \text{ Sin.} (b - x)$, and $\text{Sin.} (b - x) = \frac{\text{Sin } (b - a)}{m'}$, and the second formula, or

$\text{Sin. } x = \frac{m}{m'} \text{Sin. } a$ becomes $m = \frac{m' \text{ Sin. } x,}{\text{Sin. } a.}$

The following example, by which Boscovich illustrates the above proposition, is suited to common crown glass, and will show the application of the last formula.

$$\begin{array}{rr}
a = 15^\circ\ 10' & \\
b = 13^\circ\ 14' & \\
b - a = -1^\circ\ 56' & \\
x = 14^\circ\ 26'.\ 4 & \\
\text{Then Sin.} - 1^\circ\ 56 = & 8.528102 \\
m' = 1.602 = & 0.204662 \\
\hline
\text{Sin } b - x = 1^\circ\ 12'.\ 4 & 8.323440 \\
\text{Hence } x = 14^\circ\ 26'.\ 4 & \\
m' = 1.602 - & 0.204662 \\
\text{Sin. } x, \text{ or } 14^\circ\ 26', 4 & 9.396837 \\
\hline
 & 9.601499 \\
\text{Sin. } a, \text{ or } 15^\circ\ 10' & 9.417684 \\
\hline
m = 1.527 & 0.183815
\end{array}$$

PROP. XI.

When diverging or converging rays are incident nearly at right angles upon a plane surface, the distance of the focus of incident rays from the surface, is to the distance of the focus of refracted rays from the same surface as the sine of refraction is to the sine of incidence.

Let the rays FA, FC, diverging from F, fall on the plane surface AC of a refracting medium, and let FC be incident perpendicularly. Through A draw GAH parallel to FCD, which will be a straight line, as the ray FC suffers no refraction at C: let FA be refracted into AB, and produce BA backwards till it meets FD in f. Now Sin. of incidence, or Sin. GAF=Sin. AFC = AFf; and Sin. of refraction, or Sin. BAH=Sin. AfF. Hence FA : fA=Sin. AfF : Sin. AFf=Sin. Refraction : Sin. Incidence. If we now suppose that the point of incidence A approaches to C, and ultimately coincides with it, FA will be ultimately equal to FC, and fA to fC; consequently we have by substitution FC : fC= Sin. Refraction : Sin. Incidence.

When the rays are convergent to F, as in Fig. 12. it may be shown by the same reasoning, that fC : FC= Sin. refraction : Sin. Incidence.

PROP. XII.

When diverging or converging rays are transmitted nearly perpendicularly through a medium with parallel plane surfaces, the distance between the foci of incident and emergent rays is to the thickness of the medium, as the difference of the sines of incidence and refraction is to the sine of incidence on the first surface.

Let MN, Fig. 13. be the medium, and FA, FC, diverging rays incident, as in Prop. XI. upon the first surface AC. Let T be the point where the first refracted ray AB produced cuts FC produced, and f the point where the second refracted ray BD produced cuts FC.

Since by Prop. V. FA is a parallel to fB, we have TA : AB=TF : Tf; and on account of the parallelism of AC, Bc; TA : AB =TC : Cc, consequently TF : Ff=TC : Cc, and TF : TC=Ff : Cc. But by Prop. XI. FC : TC=Sin. refraction : Sin. Incidence; and by GEOMETRY, Prop. V. FT : TC = Sin. Incidence — Sin. Refraction : Sin. Incidence; hence by substitution, Ff : Cc = Sin. Incidence — Sin. Refraction : Sin. Incidence.

If the rays are incident in the direction DB, so as to converge to f, their focus will be F; and therefore the same result will be obtained as in the last case.

SCHOLIUM.

This proposition will be found of great use for many practical purposes in optics. The Duke de Chaulnes employed it as a method of determining the refractive power of glass in the following manner. Let MN, Fig. 14. be a plate of glass with parallel surfaces. A microscopic object placed at A will send out rays to F and D, where they will be refracted into the lines FG, DE, as if they had proceeded from C, which is now their focus. If the refractive power of the glass is small, CA will be small, and it will increase with the refractive power. By means of a compound microscope and accurate micrometers, the Duke de Chaulnes measured the distance AC in fifteen different kinds of glass, and by comparing it with the thickness AB of the plate, he obtained the ratio of the sines of incidence and refraction. In Crown glass, for example, when AB was 2 78 of an inch. AC was 1.85; and in Flint glass, when AB was 2.42, BC was 1 52. See the *Memoirs of the Academy of Sciences*, 1767, page 431.

Dr. Brewster has employed the same principle in the construction of single microscopes made of thick pieces of glass, for the purpose of removing the place of the object farther from the eye, and for other purposes; and he has suggested it as of great use in many optical experiments, when it may be required for temporary purposes to increase or diminish the convergency or divergency of rays.

SECT. III.—*On the Refraction of Rays by Bodies with Spherical Surfaces.*

PROP. XIII.

When parallel rays fall nearly perpendicularly upon a spherical surface, the distance of the focus of refracted rays from the surface is to its distance from the centre of the sphere as the sine of incidence is to the sine of refraction.

Let DA, GC, Fig. 15. be two parallel rays incident upon the *convex* surface ACB of any medium, one of which GC passes through E, the centre of the spherical surface. Having joined EA and produced it to H, and having also produced DA to K, then DAH will be the angle of incidence, and EAF the angle of refraction of the ray DA. Now in all the four cases represented in Figs. 15, 16, 17, and 18, the angle AEF is equal either to the angle of incidence, or to its supplement, and EAF is equal either to the angle of refraction or its supplement; consequently, Sin. AEF = Sin. angle of incidence, and Sin. EAF = Sin. refraction. Hence FA : FE = Sin. AEF : Sin. EAF = Sin. Incid. : Sin. Refrac. If we now suppose the point A to approach to C, it will ultimately coincide with it, and FA will ultimately be equal to FC; consequently, by substituting FC in place of FA, we have FC : FE = Sin. incidence : Sin. refraction

COR. 1. Since by the proposition we have,

FC : FE = Sin. incidence : Sin. refraction; we have,
By GEOM. Prop. VI. p. 212, FC : CE = Sin. incidence : Sin. incidence—Sin. refraction, and,
FE : CE = Sin. refraction : Sin. incidence—Sin. refraction.

COR. 2. If upon E as a centre with the radius EF, Fig. 16, we describe an arch of a circle FH, then H will be the focus of parallel rays incident in the direction *g*EA, for these rays are incident under precisely the same circumstances upon the spherical surface as the rays passing along GEC. In like manner, parallel rays passing through the centre E, and incident upon any part of the spherical surface, will have their focus in a circle HF, described round E as a centre, and with EF as a radius.

Hence it follows that rays diverging from H, or any point of the circle HF, will be refracted parallel to HE.

COR. 3. The Focus F of refracted rays is farthest from the spherical surface when the point A coincides with C. Let the geometrical focus be at *f*, Fig. 16, and *m* the index or ratio of refraction; then, by Cor. 1.

fE : CE $= m : m - 1$. But,
FE : FA $= m : 1$ Therefore,
FE : FE—FA $= m : m - 1$. Hence,
fE : CE = FE : FE—FA.

But FE—FA is less than EA or EC; and, therefore, FE is less than *f*E. The point F is consequently nearer to the spherical surface than *f*. The distance F*f*, or the difference of the distances of the focus of refracted rays incident at A and C, is called the *spherical aberration*, or the *aberration of figure*, or *sphericity*, and will be more fully illustrated in a subsequent section.

DEF. The distance FC, or the distance of the focus of refracted rays from the spherical surface, when the incident rays are parallel, is called the *principal focal distance* of the surface, and the point F the *principal focus*.

PROP. XIV.

When diverging or converging rays are incident nearly perpendicularly upon a spherical surface, the distance of the focus of incident rays from the principal focus of rays coming in the contrary direction, is to its distance from the centre of the refracting surface, as its distance from the surface is to its distance from the geometrical focus of refracted rays.

As this refraction admits of no fewer than *eight* cases, from the rays being either *convergent* or *divergent*, incident either on a *convex* or *concave* surface, and refracted either by a *dense* or by a *rare* medium, we shall take only the case represented in Fig. 19, where *diverging* rays are incident upon the *convex* spherical surface of a *dense* medium.

Let QA, QC, be two rays diverging from the point Q, and one of which QC is incident nearly perpendicularly upon the refracting spherical surface ACB. Let E be the centre of the surface, and F the principal focus of refracted rays, incident in the opposite direction. Upon E as a centre, with the radius EF, describe the arch FG, cutting QA in G. Join EG, and draw Aq parallel to GE. Then, by Prop. xiii. Cor. 2. rays diverging from G will be refracted parallel to GE, that is, in the direction Aq, consequently the ray QA passing through G will also be refracted into Aq. Now, on account of the parallelism of GE and Aq, QG : QE = QA : Qq; but the point A being supposed to approach to C, and consequently, G to F, QA will become ultimately equal to QC, and QG to QF: and, therefore, by substituting these values in the last circles, we have, QF : QE = QG : Qq.

SCHOLIUM.

The limits assigned to this article will not permit us to enter into any details respecting the various cases of the preceding proposition; but the reader will have no difficulty in deducing them from the case given. Those who wish to study the subject more in detail may consult Smith's *Optics*, vol. i. p 9. Wood's *Optics*, p. 73; but particularly, Boscovich's *Opera Pertinentia ad Opticam. &c.* tom. i. p. 325, where he shows the method of determining trigonometrically all the circumstances connected with the refraction of spherical surfaces.

The following general formula, investigated by the same author, will be found of great use in practice, viz.

$$\frac{1}{q}=\frac{m-1}{a}+\frac{1}{m}p;$$

where q = Focal distance of rays infinitely near the axis.
m = Index of refraction.
a = Radius of the refracting surfaces.
p = The distance of the radiating point.

The value of *a* is *positive* or *negative*, according as the centre of the spherical surface lies on this side, or beyond the surface in respect to the radiant point. The value of *p* is *positive* or *negative*, according as the rays *converge* or *diverge*, or as the radiating point lies on this side, or beyond the surface. The value of *q* will be *positive* or *negative*, according as the radiant point is beyond or on this side of the surface, the refracted ray in the first case *converging* to the axis, and, in the second, *diverging* from it.

SECT. IV.—*On the Refraction of Rays by Spherical Lenses.*

DEF. A *Lens* is the name given to a portion of glass, or of any other transparent substance, bounded by spherical surfaces.

1. A *Plane Lens*, shown at A, Fig. 20. is a lens in which the centres of its two surfaces are infinitely distant from it.
2. A *Spherical Lens*, or *Sphere*, shown at B, Fig. 20. is a lens having the centres of its two surfaces coincident in the centre O of the sphere.
3. A *Double Convex Lens*, shown at C, Fig. 20. has two *convex* surfaces, whose centres are at finite distances, and the centres of curvature on opposite sides of the lens. It is *equally convex*, when the radius of each surface is equal; and *unequally convex*, when the radii of both surfaces are unequal.
4. A *Double Concave Lens*, shown at D, Fig. 20. has two *concave* surfaces, whose centres are at finite distances, and the centres of curvature on opposite sides of the lens.
5. A *Plano-Convex Lens*, shown at E, Fig. 20. is bounded by a *plane* and a *convex* surface.
6. A *Plano-Concave Lens*, shown at F, Fig. 20. is bounded by a *plane* and a *concave* surface.
7. A *Meniscus*, shown at G, Fig. 20, is bounded by a *concave* and a *convex* spherical surface, which meet if continued, the centres of the surfaces being on the same side of the lens.
8. A *Concavo-Convex Lens*, shown at H, Fig. 20, has one of its surfaces concave and the other convex; but the convex surface has a less curvature, and does not meet the concave surface if continued.

The *axis* of all these lenses is a straight line MN, passing through their centre of figure or gravity, and also through the centres of their spherical surfaces. The lenses are merely represented as sections in Fig. 20.; but if we suppose these sections to revolve round MN as an axis, they will generate the different solids which they represent, and of which they are sections.

9. *Cylindrical Lens.* This lens consists of two cylindrical segments placed transversely, as shown at *a b c d*, Fig. 20, and united by their plane surfaces. It has no advantages over other lenses, and is practically useless from the difficulty of executing it.

The effects of a plane lens having already been explained in Sect. I. we shall proceed to investigate the influence of all the other lenses upon rays incident upon their surface.

PROP. XV.

When parallel rays are incident upon a sphere either of a denser or a rarer medium, the distance of their focus from the posterior or anterior surface of the sphere is *one half* the distance of the focus of rays incident on the first surface from the posterior or anterior surface of the sphere.

Let QA, QC, Figs. 21, 22. be the incident rays, and CD a diameter of the sphere, parallel to QA. Let T be their focus, after the first refraction at AC, then the point F which bisects TD will be their focus after the second refraction at GD. Let H be the intersection of the incident ray QA, and the refracted ray GF, and join EA and EG. Then, since EAG is isosceles, the angles EAG, EGA are equal, and a ray AG or GA incident at A and G, at equal angles, will be equally refracted. But on account of the parallels AH, ET, we have $HAG = FGT$, and $HAG = GTE$, consequently $GTF = FGT$, and $FT = FG$. When A therefore approaches to C, G will coincide with D, and the triangle GET becomes evanescent, GF will become equal to half the base GT, that is, DF will become half of DT.

COR. 1. Since $2FD = TD$, and $2DE = CD$, we obtain $2\,ED \pm 2\,DE = TD \pm CD$, that is, $2\,FE = TC$.

COR. 2. Since by Prop. XIII. Cor. 1. TC : CE = Sin. Incidence : Sin. Incidence—Sin. Refraction, we have 2 FE : CE = Sin. Incidence : Sin. Incidence—Sin. Refraction, or FE : CE = Sin. Incidence : 2 Sin. incidence —2 Sin. Refraction. Hence we have,

			Index of Refr.	
In a sphere of	*Tabasheer*	FE : CE =	1.11145	: 0 2229
	Water	FE : CE =	1.336	: 0,672
	Glass	FE : CE =	1.500	: 1.000
	Zircon	FE : CE =	2 000	: 2.000

When the index of refraction exceeds 2, the point F will fall within the sphere, and will coincide with E when the refracting force is infinitely great.

LEMMA.

There is within every *double convex* or *double concave* lens, a certain point called its centre, through which every ray that passes will have its incident and emergent parts parallel; but in *plano-convex* or *plano-concave* lenses, this point is removed to the vertex of the convex or concave surface; and in *meniscuses* and *concavo-convex* lenses, it is removed a little way out of them, and lies nearest the surface which has the greatest curvature.

Let R *r*, Fig. 23—26. be the centres of the surfaces A *a* of these lenses, and RE *r* their axes. Draw any two of their radii RA, *r a*, parallel to each other, and joining A, *a* the point where this line intersects, the axis will be the point E above described. For since the triangles REA, *r* E *a*, are similar, $RA : ra = RE : rE$, and therefore by GEOM. Prop. IV. or V. $RA \pm ra : ra = RE \pm rE$ (or R *r*) : *r* E; and as the three first terms of this analogy are invariable, the last *r* E must also be invariable. Hence it follows, that to whatever points in the surfaces of the lens the parallel radii RA, *r a*, are drawn, the line A *a* produced, if necessary, will always cut the axis R *r* in the same point E.

If we now suppose the ray A *a* to pass both ways out of the lens, it will be refracted equally, and in contrary directions; because RA, *r a* being perpendiculars to the surfaces at A and *a*, the angles of incidence of the ray A *a*, or *a* A, will be equal. Consequently AQ will be parallel to *a q*. In plano-convex or plano-concave lenses, one of the radii RA or *r a* becomes infinite, and consequently parallel to the axis RE, the other radius will therefore also coincide with the axis, and the points A, E, or *a*, *c*, will coincide in the vertex of the convex or concave surface.

COR. When the thickness of a lens is inconsiderable, and when a ray falls nearly perpendicularly upon it, the path of the ray through E, viz, QAE $a\,q$ may be taken as a straight line passing through the centre E of the lens; for the perpendicular distance of AQ and $a\,q$ diminishes both with the thickness of the lens, and with the obliquity of the ray to the axis.

Prop. XVI.

To find the principal focus, or the focus of parallel rays falling perpendicularly upon a lens whose thickness is inconsiderable.

In the six different kinds of lenses, shown in Figs. 1—6, let E be their centre, R r their axis, passing through the centres R, r of their surfaces. Let g EG be a line parallel to the rays incident upon the surface B. Draw the radius BR parallel to g E, and in BR produced let V be the focus of the rays after their first refraction at the surface B, and having joined V r, the point G where it cuts g E will be the focus of rays refracted by the lens. Since V is the focus of the rays incident upon the second surface A, the refracted rays must have their focus in some point of the line V r, drawn through r perpendicular to that surface, consequently the focus of all the rays must be at the intersection G of the ray g EG with the ray V r.

Cor. 1. If the inclination of the incident rays to the axis of the lens is gradually diminished till they become parallel to it, the focal distance EF will be equal to EG. In passing from GE to FE, the first and second foci V and G will describe circular arcs VT, GF, having their centres in R and E. For as RV is to RB, as the lesser of the sines of incidence and refraction is to their difference, the line EG will be invariable, being to the given line RV in the given ratio of r E to r R, on account of the similar triangles EG r, RV r.

Cor. 2. The following rule, for determining the focal distance of a thin lens, is deducible from the similarity of the triangles EG r, RV r. As the interval between the centres of the surfaces, or R r, is to the radius of the second surface r E, so is the continuation of the first radius to the first focus, viz. RV or RT, to the focal distance of the lens EG or EF, which must be on the same side as the emergent rays, if the lens is thicker in the middle than at its edges, and on the opposite side, if it is thinner in the middle; that is,

$$\mathrm{R}r : r\,\mathrm{E} = \mathrm{RT} : \mathrm{EF}\text{ ; and }\mathrm{EF} = \frac{r\,\mathrm{E} \times \mathrm{RT}}{\mathrm{R}\,r}.$$

Cor. 3. The distance of the principal focus of a lens from its centre F, is the same on each side of the lens, that is, EF and E f are equal, when rays fall on both sides of the lens. Continue E r to t, the first focus of rays falling parallel upon the surface; and since r R : r E = RT = EF, we shall for the same reason have r R : RE = $r\,t$: E f. Consequently, since the rectangle under r E, RT, and also RE, $r\,t$, are equal, we shall have E f = EF; for r E : $r\,t$, and RE : RT, in the same given ratio.

Cor. 4. The focal length of a *double convex* or *double concave* lens of *glass*, whose index of refraction is 1 500, is equal to the radius of the surface. Since by Prop. XIII. Cor. 2. BR : RV = Sin Incid.—Sin. Refract. : Sin. Incid. that is, BR : RV = 1.5 — 1 : 1 = 0.5 : 1 = 1 : 2, and RV = 2 BR. But because BR = A r, we have A r : BR + A r : 1 : 2 = RV : EG = 2 BR : EG. Consequently, EG = BR.

Cor. 5. In *plano-convex* and *plano-concave* lenses of *glass*, the focal length is equal to the diameter of the spherical surface; in this case the centre r of the plane surface is infinitely distant, and V r is parallel to ER. Consequently GERV is a parallelogram, and EG = RV = 2 BR.

Cor. 6. In *Zircon*, *Sulphur*, and other bodies, whose index of refraction is 2.000, it may be shown by the same reasoning as in the two preceding corollaries, that the focal length of *double convex* and *double concave* lenses is equal to *half the radius* of either surface, and that in *plano-convex* lenses it is equal to the *radius* of the spherical surface.

Prop. XVII.

When diverging or converging rays are incident upon a spherical lens, to find the focus of emergent rays.

Let a pencil of rays diverge from a radiant point Q, Figs. 7, 8, 9, 10, and fall upon a lens or sphere whose centre is E. Let F be the focus of parallel rays incident upon the lens in the opposite direction; then make E f = EF, and say, as QF : FE = E f : $f\,q$, which gives $f\,q = \frac{\mathrm{FE} \times \mathrm{E}f}{\mathrm{QF}}$. Let $f\,q$ thus found be set in the opposite way from f that Q is from F, and the point q will be the focus of refracted rays.

Upon E as a centre, and with the radius EF or E f describe the arches FG, $f\,g$, cutting any ray QA q in G and g, and join EG and E g. Then, supposing rays such as GA to diverge from G, the convergent rays $a\,g\,q$ will, by Prop. XIII. Cor. 2. be parallel to GE, and the triangles QGE, $q\,g$E will be similar. Hence QG : GE = E g : $g\,q$. But if we suppose QA to approach gradually to QE, $q\,a$ will also approach to q E, and we shall ultimately have QG = QF, GE = FE, EG = E f, and $g\,q = f\,q$. Consequently we have ultimately, or for rays near QE q, QF : FE = E f : $f\,q$.

Cor. 1. When Q approaches to F, so as to coincide with it, the refracted or convergent rays become parallel, or, which is the same thing, q recedes to an infinite distance; and when Q passes to the other side of F, the focus q will also pass to the other side, or to the same side with F.

Cor. 2. On account of the similarity of the triangles QGE, QA q, QG : QE = QA : Q q, or ultimately QF : QE = QC : Q q.

Cor. 3. Since in the analogy QF : FE = E f : $f\,q$, the middle term, or the rectangle under FE and E f is invariable, the distance $f\,q$ varies reciprocally as FQ, and the points q, Q lie in opposite directions from f and F.

Cor. 4. When the foci Q q lie on the same side of the lens, if the incident rays diverge from Q, the refracted rays will also diverge from q; and if the incident rays converge to Q, the refracted rays will also converge to q. When Q and q are on opposite sides of the lens, the contrary will happen. The points Q and q are called the *Conjugate Foci.*

Scholium.

As our limits will not permit us to enter into any farther details on this branch of the science, we shsll lay before our readers the formulæ for the foci of lenses, as deduced analytically by the celebrated Dr. Halley.

In these formulæ we have
$m : n =$ the ratio of refraction.
$d =$ distance of the object, or of the radiant point.
$r =$ the radius of the surface next the object.
$\varrho =$ the radius of the surface next the image.
$t =$ thickness of the Lens.
$f =$ focal length of the Lens.

General Formulæ.

$$f = \frac{m p d r \varrho - n d \varrho t + n p r \varrho t}{m d r + m d \varrho - m p r \varrho - m - n . d t + n r t}.$$

$$f = \frac{12 d r \varrho - 3 d \varrho t + 9 r \varrho t}{4 d r + 4 d \varrho - 12 r \varrho - d t + 3 r t}.$$ For *Water*, whose index of refraction is nearly 1.3333, or $m : n = 4 : 3$.

$$f = \frac{6 d r \varrho - 2 d \varrho t + 4 r \varrho t}{3 d r + 3 d \varrho - 6 r \varrho - d t + 2 r t}.$$ For *Glass*, whose index is 1.500, or $m : n = 3 : 2$.

$$f = \frac{\frac{10}{3} d r \varrho - 2 d \varrho t + \frac{4}{3} r \varrho t}{5 d r + 5 d \varrho - \frac{10}{3} r \varrho - 3 d t + 2 r t}.$$ For *Diamond*, whose index is 2.500.

Formulæ when the Thickness of the Lens is omitted.

$$f = \frac{p d r \varrho}{d r + d \varrho - p r \varrho}.$$ For *diverging* rays, which becomes $f = \frac{p r \varrho}{r + \varrho}$ for *parallel* rays.

$$f = \frac{p d r \varrho}{d r + d \varrho - 2 r \varrho}.$$ For *Glass*, whose index of refraction is 1.500.

$$+ f = \frac{- 2 d r \varrho}{- d r - d \varrho - 2 r \varrho}.$$ For *converging* rays falling on a *double convex lens* of *glass*.

$$f = \frac{- 2 d r \varrho}{- d r + d \varrho + 2 r \varrho}.$$ For *diverging* rays falling on a *meniscus of glass*, f being positive when $2 r \varrho$ is less than $d r - d \varrho$, otherwise negative.

$$f = \frac{+ 2 d r \varrho}{+ d r - d \varrho + 2 r \varrho}.$$ For *converging* rays falling on a *meniscus of glass*, f being positive when $d \varrho - d r$ is less than $2 r \varrho$, but if greater, f is negative.

$$f = \frac{- 2 d r \varrho}{+ d r + d \varrho - 2 r \varrho}.$$ For *converging* rays falling on a double *concave lens* of *glass*, f being always negative, excepting when $2 r \varrho$ exceeds $d r + d \varrho$.

$$- f = \frac{2 d r \varrho}{d r + d \varrho + 2 r \varrho}.$$ For *diverging* rays falling on a *double concave lens* of glass.

$$f = \frac{p d r}{d - p r}.$$ For *diverging* rays falling upon a *plano-convex lens* of *glass*.

$$f = \frac{p d r}{2 d - p r}.$$ For *diverging* rays falling on an *equally double convex lens* of *glass*.

$$f = \tfrac{1}{2} p r.$$ For *parallel rays* falling on the last lens of glass.

$$d = \frac{12 r \varrho f}{r f + \varrho f - p r \varrho}.$$ To find d the distance of the object.

$$\varrho = \frac{d r f}{p d r + d f + p r f}.$$ To find ϱ one of the radii.

$$p = \frac{n}{m - n} = \frac{d r f + d \varrho f}{d \varrho r + f \varrho r}.$$ To find the *Index* or ratio of refraction.

Before we conclude this section on the focal lengths of lenses, we shall describe the method employed by Dr. Smith for illustrating experimentally the motion of *conjugate foci* along the axis of a lens.

Having determined the focal distance EF of a convex lens of glass E, Fig. 11. and fixed it on a thin piece of wood CE, placed vertically on a long table or floor, draw a long line AB perpendicular to the board, and through the point C, and on this line, lay down the focal distance of the glass from C to F, and set the same distance from F to I, I to II, II to III, &c. and also on the other side of C from C to f, from f to 1, 1 to 2, 2 to 3. Let $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, &c. of the focal distance be next taken, and set from F towards I, and also from f towards 1, and put the numbers $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, &c. to the points of division, as in Fig. 11. Things being thus prepared, darken the room, and place a candle at Q over the mark I. The rays transmitted through the lens will converge at q upon a piece of paper held over the opposite mark 1. If the candle is removed to II, and the paper to $\frac{1}{2}$, the rays will there also be converged into a distinct image; and in like manner it will be found, that when the candle is at III, the distinct image will be at $\frac{1}{3}$, at IV, and $\frac{1}{4}$, &c. the effect remaining exactly the same if the paper and the candle be made to change places Hence it is obvious that $f g$ varies reciprocally as FQ; that is, it increases in the same proportion as FQ increases, and *vice versa*.

SECT. V.—*On the Refraction of Rays to a single Point by Elliptical, and Hyperbolical, and other Lenses.*

From the truths demonstrated in the two preceding sections, it is manifest that those rays which are incident near the axis of a lens, or of a spherical surface, are converged to a different focus from those which fall at a distance from the axis. This error, or deviation of the rays from a mathematical point, is called the *Spherical Aberration.*

As the convergence of the incident rays to one focus is essentially necessary to the perfection of images formed by optical instruments of all kinds, it has been proposed, as we have already seen in the History of Optics, to use lenses generated by the revolution of the *ellipse* or *hyperbola.* In compound lenses, whose diameter is considerable, the accurate convergence of the rays may be effected by a proper adjustment of the surfaces of spherical lenses, as will be afterwards shown; but this mode of producing an exact convergence of the rays to a single focus is impracticable in small lenses, such as are used in microscopes and eye-pieces; and therefore we have no doubt but that the ingenuity of opticians will again be turned to the construction of elliptical and hyperbolical lenses, the theory of which we shall now proceed to explain.

PROP. XVIII.

A meniscus has the property of refracting all converging rays if its first surface is convex, or all diverging rays if its first surface is concave, to a single focus, provided the distance of the radiating point from the centre of the first surface is to the radius of the first surface, as the sine of the angle of incidence is to the sine of the angle of refraction.

Let MADN, Fig. 12. be a meniscus, and QABC, Q'A'B'C rays converging to the point C. Take the point F, so that CE : EA = Sin. Incidence : Sin. Refraction, and from F, with any radius FB less than FA, describe the circle MBB'N, the rays QA Q'A, and all others, will be refracted accurately to the point F, so that the lens is entirely free of *spherical* aberration. Since Sin. Incidence : Sin. Refraction = CE : EA = Sin. CAE : ACE, and since CAE is equal to the angle of incidence, ACE must be equal to the angle of refraction, that is, to EAC. But the angle AEC is common to the two triangles, ACE, AFE, consequently the triangles are similar, and CE : EA = EA : EF; and as the three first terms of this analogy are constant, EF is also constant, and all the refracted rays will meet the axis in the same point F. But as these rays converge to F the centre of the spherical surface MBN, they will fall perpendicular upon that surface, and will therefore pass on to F without suffering any farther change in their direction.

When diverging rays fall under similar circumstances upon the concave surface of a lens, the proposition is proved in the very same manner.

PROP. XIX.

If a lens has its anterior surface part of a prolate spheroid formed by the revolution of an ellipse, whose greater axis is to the distance between its foci as the sine of incidence is to the sine of refraction, and if the other surface is concave, and part of a sphere whose centre is the farther focus of the spheroid, a pencil of rays, parallel to the axis of the spheroid, will be refracted, so as to converge accurately to the farther focus of the spheroid.

Let PDQ, Fig. 13. be the lens, whose anterior surface PDQ is part of a prolate spheroid, generated by the revolution of the ellipse PDQK about it major axis DK, having H and I for its foci, and let is posterior surface PQ, placed at any distance between D and I, have I for its centre, the rays AB, MD, parallel to the axis DK, will be refracted accurately to the focus I. Having joined HB, IB, draw EBC, touching the generating ellipse in B, and through B draw GBL perpendicular to EBC, and cutting DK in N. Since by the nature of the ellipse, (CONIC SECTIONS, Prop. viii) HBC = IBE, and NBC = NBE, we have HBN = INB, and by GEOMETRY, Prop. XVII.

IB : BH = IN : NH,
GEOM. Prop. IV. IB : IB + BH (DK) = IN : IH, and
GEOM. Prop. III. IB : IN = DK : IH
But by hypothesis DK : IH = Sin. Incidence : Sin. Refraction, hence
IB : IN = Sin. Incidence : Sin. Refraction,
But IB : IN = Sin. INB : Sin. IBN = Sin. BNH or Sin. ABG : Sin. IBL.
Consequently, Sin. ABG : Sin. IBL = Sin. Incidence : Sin. Refraction.

But Sin. ABG is the Sine of incidence, consequently Sin. IBL is the Sine of refraction, and BI is the ray refracted by the speroidal surface PDQ. But since PQ is a spherical surface, whose centre is I, the ray BI will fall perpendicularly upon it, and will therefore pass on to I without suffering any farther refraction.

In the very same manner it may be shown, that every other ray of a pencil, parallel to AB, will be refracted to the same point I.

The same property may be shown by similar reasoning to belong to a concave lens, whose first surface MKN, Fig. 13. or that which receives the parallel rays AB, is part of a prolate spheroid; but the second surface OR must be spherically convex, and have H for its centre.

COR. Rays diverging from I, will, after refraction through the lens, be parallel to ID.

PROP. XX.

If a lens has its posterior surface part of a hyperboloid, formed by the revolution of a hyperbola, whose greater axis is to the distance between the foci, as the sine of incidence is to the sine of refraction; and if the other surface is plane, a pencil of rays parallel to the axis of the spheroid will be refracted so as to converge accurately to the farther focus of the spheroid.

Let PDQ, Fig. 14. be the lens, whose posterior surface PDQ is part of a hyperboloid, (generated by the revolution of the hyperbola PBDQ, about its major axis DK, having H and I for its foci,) and whose other surface PQ is plane, and perpendicular to DK, the parallel rays AB, MD, will be refracted to its farther focus I. Having joined HB, IB, then by constructing the diagram as in Prop. XIX. it may be shown by almost the same steps that the ray AB, which suffers no refraction at all, by falling at right angles upon the plane surface PQ, will be refracted by the hyperboloidal surface to the focus I.

The same property may be shown to belong to a plano concave lens P′ Q′ *q p*, having one hyperbolic surface P′KQ′, and a plane surface *p q*, upon which the incident rays fall perpendicularly.

Prop. XXI.

To determine the figure of a refracting surface which shall refract accurately to one point all the incident rays.

Let A, Fig. 15. be the point from which the rays AK, AD diverge, B the focus in which it is required to unite them after refraction, and let D be taken at pleasure as the summit of the surface which is to refract them. From A and B, as centres, and with the radii AD, BK, describe the circles DX, KY, then they will all meet in one point B, provided the curve KGD is such that lines AK, KB, drawn from any point K, have such a ratio that the excess of AK above AD or KX, shall be to that of BD above BK, or DY, as the sine of incidence is to the sine of refraction. Take the point G infinitely near K, so that K G may be considered as a tangent to the curve at the point K, and draw ZKH perpendicular to it, so that AKZ will be the angle of incidence, and BKH the angle of refraction. Now, since in every point of the curve the difference between AK and AD is to the difference between BD and BK, in the same ratio, the difference of lines infinitely near to KA, viz. AG and BG will be in the same ratio; that is, GQ : GL = : Sin. Incidence. Sin. Refraction; but LGQ, and GKQ, are respectively equal to AKZ and BKH, the angles of incidence and refraction; consequently KL and KQ, which are the sines of the angles LGQ, GKQ, being to one another as the sine of incidence to the sine of refraction, it follows that the sines of the angles AKZ and BKH are in the same ratio, and therefore that KB is the refracted ray when AK is the incident ray.

In order to describe this curve, viz. KD, Fig. 16. take in the line AB any point C, and let CD be divided at the point E, in such a manner that DE : DC, as the sine of refraction is to the sine of incidence. From the point A, and with AC as radius, and from the point B with the radius BE, describe circles C *c*, E *e*, and their intersection, or the point K, will be a point in the curve required; for it is obvious that AK will decrease, and BK increase, in such a manner that their respective increments and decrements will be in the same ratio as DC and DE, which is the property found in the proposition. See Newton's *Lectiones Opticæ*, part i sect iv. Prop. xxxiv. p. 141.; Montucla's *Histoire des Mathematiques*, &c. tom. ii. p. 260 and 266; and Huygens's *Traité de la Lumiere*, p. 111.

Prop. XXII.

To determine the figure of one side of a lens, which shall refract incident rays accurately to one focus, when the other side of the lens is given, and is such that tangents can be drawn to it.

Let the figure of the given surface be such as is generated by the revolution of the curve KAK, Fig. 17. round the axis AV, and let this surface AK receive the rays diverging from the point L. Let AB, the thickness of the lens, be also given, and let F be the focus to which all the rays are to be accurately converged, whatever may have been the refraction of the first surface AK.

If LG is one of the rays incident at G, its refracted ray GV will be determined by means of the index of refraction of the medium, and a tangent drawn to the curve at G. We must therefore find in the line GV a point D, so that $FD+m\times DG$ shall be equal to a given line; and in like manner for any other ray LM, refracted into MO, we must find a point N, so that $FN+m\times MN$ shall be equal to the same given line, m representing the index of refraction. For the demonstration of this proposition, which is not of much practical utility, we must refer the reader to Huygens's *Traité de la Lumiere*, p. 114, 115.

Sect. VI.—*On the Formation of Images by Plane and Spherical Lenses.*

Prop. XXIII.

The image of any object formed by a plane lens is equal and similar to the object, and in a similar situation on the same side of the lens.

Let A *a b* B be a plane lens, PQ the object, and PA, PC, two rays from P, incident upon the lens, and QB, QC, two rays from Q, incident upon the lens. The rays PA, QB, being supposed to fall perpendicularly, will pass on unrefracted to *a* and *b*, but the rays PC, and QC, will be refracted at C in the direction C *e*, C *d*, and will again be refracted at the second surface, so as to emerge at *d* and *e*, parallel to PC and QC, as if they had come from the points *p* and *q*, determined by drawing *e p* and *d q* parallel to PC and QC. As the distances P *p* and Q *q* depend solely upon the thickness of the glass, and upon its refractive power, these will be invariable for the different points of the object, and consequently *p q* will be equal and parallel to PQ.

Prop. XXIV.

An image formed by a prism is upright, and equal to the object, and lies on the same side of the prism, and at the same distance from it as the object, provided the refracting angle of the prism and its refractive power be small.

Let two rays PE, QE, from the extremities of the object PQ, pass through the point E, so near the summit of the prism ABE, that the distance between the points of incidence and emergence is very small. Now since the total refractions of the rays PEN, QEO are equal, they will cross each other, so that the angle PEQ=NEO=*p* E *q* formed by the emergent rays produced backwards, and because the distance E*p*=EP, and E *q*=EQ, the image *p q* will be upright, and of the same size as the object, and at an equal distance on the same side of the prism.

Prop. XXV.

If an object placed before a lens has the form of a circular arch, whose centre is that of the lens, its image will be a similar concentric arch; the length of the object will be to the length of the image as their distances from that centre, and the image will be erect or inverted, according as it lies on the same, or on the opposite side of the centres.

Let AB, Fig. 20. Plate CCCCXXIX. and Figs. 1, 2. Plate CCCCXXX. be the lens, and E its centre, and let the object PQR have the form of a circular arch, whose centre is E. In PQR, take any point Q, and having joined QE, let F be the principal focus of rays incident in the opposite direction. In QE, produced if necessary, take $QF : FE = QE : Eq$, and setting q E from E to q, q will be the image of the point Q. Upon E as a centre, with the radii EF, E q, describe the circular arcs GFH, $p\ q\ r$, and draw PE, RE meeting $p\ q\ r$ in p and r; then $p\ q\ r$ will be the image of the object PQR. Since $EP = EQ$, and $EG = EF$, we have $EP \pm EH = QE \pm EF$; that is, $PH = QF$; but by the construction $Ep = Eq$, and $QF : FE = QE : Eq$; consequently $PH : HF = PE : Ep$, or p is the image of the point P. In like manner it may be shown, the angle PER being always supposed small, that every other point in PQR will have its image in a corresponding point of $p\ q\ r$. As the arches PQR, $p\ q\ r$ subtend equal angles at E, they are similar. Since the axes RE r, PE p of the incident pencils are reckoned straight lines, passing through E, the angle $PER = pEr$, and consequently $PR : pr = PE : pE = QE : Eq$. As the points r and p are necessarily in the axes RE r, PE p, they will be on the same or on contrary sides of E, according as their middle points Q q, are on the same or on contrary sides of F; that is, the image will be erect or inverted, according as these points are on the same or on the contrary sides of E.

Cor. As the object PR approaches nearer to a straight line in proportion to the smallness of the angle which it subtends at E, a small rectilineal object placed at a considerable distance from the centre of the glass may be supposed to have very nearly a straight image.

Prop. XXVI.

The image of a rectilineal object, formed by a lens or sphere, is the arc of a conic section, being an *ellipse*, a *parabola*, or a *hyperbola*, according as the distance of the object is *greater* than, *equal* to, or *less* than, the principal focal distance of the lens or sphere.

Let AB, Figs. 3, 4, 5. be a lens or sphere, whose centre is F, PQZ a rectilineal object placed before its focus F, as in Fig. 3. between the focus and the lens, as in Fig. 4. or in the focus, as in Fig. 5. Through E draw QE q, at right angles to PZ, and in PZ take any point P, and having drawn PE, produce it towards p. Let F be the principal focus of rays incident in the opposite direction, and upon E as a centre, with the radius EF, describe the circles FG f L, cutting PE in G. In the line PE p, take $PG : PE = PE : Pp$, setting P p to the left hand of P, if G is to the left hand of p, as in Fig. 4. then p is the image of the point P. Draw p D parallel to Q q, and on account of the similarity of the triangles PEQ, P p D.

$PE : Pp = QE : Dp$

Consequently, $PG : PE = QE : Dp$. But

$PG : FE = PE : Ep$, and

Geom. Prop. III. $PG : PE = DE$ (or FE); Ep,

Consequently, $QE : Dp = FE : Ep$, and

Geom. Prop. III. $QE : FE = Dp : Ep$.

Hence E p, the distance from the focus, bears a constant ratio to D p, the distance from the directrix PQ, and consequently p is a point in a conic section, whose focus is E, and whose directrix is PQ. See Conic Sections.

Sect. VII.—*On Spherical Aberration, and Caustic Curves produced by Refraction.*

We have already seen, in the preceding section, that rays passing near the centre of a lens have a different focus from those which pass near its circumference, and that incident rays can only be refracted to a mathematical focus by means of lenses having the form of the conic sections, or the compound figures already described. As it is necessary, however, in practice to use spherical surfaces, it becomes of importance to determine the exact amount of spherical aberration under different circumstances, and to explain the methods by which it may be diminished or corrected by opposite refractions.

Def. Let AB, Fig. 6. be a lens receiving the parallel rays NA, EP, F the focus of the central rays EP, and f the focus of the marginal rays NA; then having drawn through F the line FG, perpendicular to the axis ECF of the lens, F f is called the *Longitudinal Spherical Aberration*, and FG the *Lateral Aberration*. AB is called the *Aperture*, and AC the *Semi-aperture* of the lens.

Prop. XXVII.

When parallel homogeneous rays are incident upon a spherical surface, the longitudinal aberration is to the versed sine of the semi-aperture, as the square of the sine of refraction is to the rectangle of the sine of incidence, and the difference of the sines of incidence and refraction very nearly.

Let ACB, Fig. 6. be a spherical surface, separating two refracting media, E its centre, C its vertex, AC its semi-aperture, AP the sine of the semi-aperture, PC the versed sine of the semi-aperture, and F the focus of parallel rays infinitely near the axis. Let the extreme marginal ray NA be refracted in the direction AG, crossing CE in f, which will therefore be the focus of extreme parallel rays. Join EA, and having prolonged GA towards M, let fall the perpendiculars EM, EN upon the lines AN, AM; upon f as a centre, with the radius f A, describe the arch AD. The angle EAN is the angle of incidence, and EAM or EA f the angle of refraction, and EN and EM are the sines of incidence and refraction, which we shall call n and m

Then, because the triangles E f M and A f P are similar, we shall have

$Ef : fA$ or $fD = EM : AP$, or EN; but by Prop. XIII

$EM : EN = EF : FC$. Hence,

$Ef : fD = EF : FC$.

By Geometry, Prop. VI.
$Ef : Ef - fD = EF : EF - FC$, that is,
$Ef : ED = EF : EC$, and by Geometry, Prop. II. and III.
$EF : Ef = EC : ED$, and by Geometry, Prop. V.
$EF - Ef : EF = EC - ED : EC$; that is, by substitution,
$Ff : EF = DC : EC$, and by Geometry, Prop. III.
$Ff : DC = EF : EC = EM : EN = m : m - n$

But since the versed sines PD, PC, of small arches AD, AC of unequal circles that have the same right sine AD, are reciprocally proportional to their radii Df, EC, we have

$$PD : PC = CE : Df.$$

But as the point A approaches to C, FC approaches to equality with Df, and may therefore be assumed as nearly equal to it, we have

$$PD : PC = CE : FC,$$

and by Geometry, Prop. IV.

$$DC : PC = EF : FC = m : n.$$

But we had formerly

$$Ff : DC = m : m - n,$$

Hence, by compounding these ratios, we have

$$Ff : PC = m^2 : mn - n^2, \text{ and}$$

$$Ff = FC \times \frac{m^2}{mn - n^2}, \text{ or (making } d = m - n) = \frac{m^2}{d\,n}$$

Cor. 1. When the refraction is made from a dense to a rare medium, then m will be the sine of refraction, and n that of incidence, consequently the aberration will be,

$$\frac{n^2}{m^2 - m}, \text{ or } \frac{n^2}{d\,m}.$$

Hence we have,

$$\frac{m^2}{d\,n} : \frac{n^2}{dm} = \frac{d\,m^3}{d^2mn} : \frac{d\,n^3}{d^2m\,n} = m^3 : n^3;$$

that is, the aberration is always less when the refraction is made from a rare into a dense medium, in the ratio of m^3 to n^3.

Cor. 2. *In refractions from a dense to a rare medium*, if we make $m : n = 112 : 100$, as it is from *Tabasheer* to *Air*, then $\frac{n^2}{dm}$, and consequently the *longitudinal aberration* of parallel rays, or $Ff = : \frac{125}{12}\,PC = 10\frac{1}{2}\;PC$, or $10\frac{1}{2}$ times the *thickness* of the lens.

If $m : n = 112 : 100$, as it is in *Tabasheer*, then $Ff = 10\frac{1}{2}$ PC.
If $m : n = 4 : 3$, as it is in *Water*, then $Ff = 5\frac{1}{3}$ PC.
If $m : n = 3 : 2$, as it is in *Crown Glass*, then $Ff = 4\frac{1}{2}$ PC.
If $m : n = 3.2333 : 2$, as in *Flint Glass*, then $Ff = 4\frac{1}{4}$ PC.
If $m : n = 4 : 2$, as in *Zircon*, then $Ff = 4$ PC.
If $m : n = 5 : 2$, as in *Diamond*, then $Ff = 4\frac{1}{6}$ PC.
If $m : n = 6 : 2$, as it is nearly in *Chromate of Lead*, $Ff = 4\frac{1}{2}$ PC.

Hence we observe a curious law in the aberration when the thickness of the lens is constant, and the refractive power varies. The spherical aberration or refraction from a dense into a rare medium, is a *maximum* in *air*, when the refractive power is nearly a *minimum*. It then gradually increases in all substances up to *Zircon*, when d becomes equal to n, or when the difference of the sines of incidence and refraction is equal to the sine of incidence, and then it is a *minimum*. It next gradually increases, and becomes a maximum, when the refractive power is infinitely great.

Cor. 2. *In refractions from a rare to a dense medium*, as it is from air to *Tabasheer*, then $\frac{m^2}{dn}$ becomes $= \frac{10000}{1344}$, and consequently the *longitudinal aberration* of parallel rays is as follows:

If $m : n = 112 : 100$ as in *Tabasheer*, then $Ff = 7.45$ PC.
If $m : n = 4 : 3$, as in *Water*, then $Ff = 2\frac{1}{4}$ PC.
If $m : n = 2 : 3$, as in *Crown Glass*, then $Ff = 1\frac{1}{5}$ PC.
If $m : n = 3\,2333 : 2$, as in *Flint Glass*, then $Ff = 1$ PC.
If $m : n = 4 : 2$, as in *Zircon*, then $Ff = \frac{1}{2}$ PC.
If $m : n = 5 : 2$, as in *Diamond*, then $Ff = \frac{1}{375}$ PC.
If $m : n = 6 : 2$, as in *Chromate of Lead*, then $Ff = \frac{1}{6}$ PC.

Hence it appears, that in refractions from a rare into a dense medium, the aberration diminishes with the refractive power, and with great rapidity.

Cor. 3. The segment APBC may be considered as a plano-convex lens, upon whose plane side the rays are incident. Hence the aberration of such a lens, in such a position, will be $4\frac{1}{2}$ times PC in crown glass, whose index of refraction is 1.50, or $\frac{3}{2}$, and for other substances as in the first of the preceding Tables.

Cor. 4. We may obtain the aberration in terms of the semi-aperture, by considering that $PC : AP = AP : 2\,EC$, Euclid, vi. 13. we have $PC = \frac{AP^2}{2\,EC}$ nearly, and that by Prop. XIII. p. 637, $EC = \frac{m-n}{n} \times CF$. Hence we have

$$Ff = \frac{m^2}{m\,n - n^2} \times \frac{AP^2}{2\,EC} = \frac{m^2}{(m-n)^2} \times \frac{AP^2}{2\,CF}.$$

Cor. 5. Drawing FG perpendicular to the axis, we shall have $FG : Ff = AP : fP$, or CF, or $\frac{n}{m-n} \times CE$. Hence we obtain $FG = \frac{m^2}{n^2} \times \frac{AP^3}{2\,EC^2} = \frac{m^2}{(m-n)^2} \times \frac{AP^3}{2\,CF}$.

Cor. 6. When the radius of the refracting surface, or the focal length, is given, the *longitudinal aberrations* are as the squares, and the *lateral aberrations* as the cubes, of the linear aperture of a plano-convex lens.

Cor. 7. In the same medium, and with the same spherical surface, the aberration varies as the versed sine of the semi-aperture.

Prop. XXVIII.

When parallel homogeneous rays fall upon a plano-convex lens, the diameter of each circle of aberration is equal to *one-half* the lateral aberration of the extreme ray.

Let $a\,y\,f'$, Fig. 7, be a refracted ray, cutting the axis ECT in f', and the extreme ray $\mathrm{A}\,f\,\mathrm{G}$ in y. Draw $x\,y$ perpendicular to the axis. Then as the point of incidence a recedes from the vertex c, the focus f of parallel rays will shift from F to f, where it will arrive when $a\,\mathrm{C} = \mathrm{CA}$; hence $x\,y$ will first increase, because the arch $a\,\mathrm{C}$ constantly increases, and it will afterwards decrease on account of the continual diminution of the line $f\,f'$. At the time when it reaches its maximum, all the rays incident on CB will obviously pass through it. In order to determine this maximum value, let $q\,a$ cut PB in b, and calling $\mathrm{P}b = v$, $f\,x = z$, $\mathrm{PA} = c$, $\mathrm{P}\,f = d$, $f\,\mathrm{F} = g$. Then by Cor. 6. Prop. XXVII. we have the aberration $\mathrm{F}\,f : g = c^2 : v^2$, and $\mathrm{F}\,f' = \frac{v^2}{c^2}g$. Consequently,

$$f\mathrm{F} - \mathrm{F}\,f' = f\,f' = \left(\frac{g}{c^2}\right)c^2 - v^2.$$

But $\mathrm{P}\,f : \mathrm{PA} = f\,x : x\,y$;

or by substitution,

$$d : c = z : \frac{c\,z}{d}.$$

Likewise $p\,a : p\,f'$ or $\mathrm{P}\,f = x\,y : x\,f'$;

or by substitution of symbols;

$$v : d = \frac{c\,z}{d} : \frac{c\,z}{v}.$$ Hence we obtain,

$$f\,f', \text{ or } x\,f' + x\,f = \frac{c\,z}{v} + z = \left(\frac{g}{c^2}\right)c^2 - v^2.$$

$$\text{Consequently } \frac{z}{v}(c+v) = \frac{g}{c^2}(c+v)(c-v),$$

$$\text{And } z = \frac{g}{c^2}v(a-v).$$

Hence it follows, that $f\,x$ is a maximum when the quantity $v\,(c-v)$, or $\mathrm{P}\,b \times b\,\mathrm{B}$ is a maximum; that is, Euclid, vi. 13. when $\mathrm{P}\,b = b\mathrm{B}$, or when $v = \frac{1}{2}\,c$. If we now substitute this value of v in the last equation, we obtain the maximum value of $z = \frac{1}{4}\,b$, or the greatest value of $f\,x = \frac{1}{4}\,f\,\mathrm{F}$. Hence, since $f\,x : x\,y = f\,\mathrm{F} : \mathrm{FG}$, the greatest value of $x\,y = \frac{1}{4}\,\mathrm{FG}$, and if $x\,y$ denotes a circle about the axis $\mathrm{P}\,x$, it will be the circle of aberration through which all parallel homogeneous rays incident upon AB must necessarily pass.

Prop. XXIX.

When diverging or converging homogenous rays are incident upon a spherical surface, to determine the spherical aberration.

Let R be the radiant point, and F its conjugate focus, and let the ray RD be incident upon the spherical surface DO, whose radius is SO. Let the refracted ray DK cut the axis RO in K; let DX be the sine of the arch D o, and put $\mathrm{R} = \mathrm{RO}$, $\mathrm{S} = \mathrm{SO}$, and $\mathrm{X} = \mathrm{XO}$, and $m : n = $ Sin. Incidence : Sin. Refraction; and $d = m - n$.

Through S draw BSZM parallel to RD, and cutting DK produced in Z, draw SA perpendicular to RD, and let t and M be the foci of refracted rays, whose parallel incident rays fall nearest to the radii SO, SB. Then by Prop. XIII. p. 637, we have SM or $\mathrm{S}\,t = \mathrm{SO}\frac{n}{d}$ and if the incident ray RD were parallel to SO, then its aberration, or $t\,y = \frac{n^2}{md}\mathrm{XO}$; and by Prop. XXVII. p. 644, Cor. 6. the aberration $\mathrm{MZ} : t\,y = \overline{\mathrm{SA}}^2 : \overline{\mathrm{DX}}^2 = \overline{\mathrm{RS}}^2 : \overline{\mathrm{RO}}^2$.

Hence we have,

$$\mathrm{MZ} = \frac{(\mathrm{RO} - \mathrm{SO}^2)}{\mathrm{RO}^2} \times \frac{n^2}{m\,d}\mathrm{XO}, \text{ and } \mathrm{SZ} = \frac{n}{d}\mathrm{SO} - \mathrm{MZ}.$$

But on account of the similarity of the triangles RKD, SKZ, we have

$$\mathrm{RK} : \mathrm{SK} = \mathrm{RD} : \mathrm{SZ}.$$

By Geom. Prop. IV. $\mathrm{RK} : \mathrm{RS} = \mathrm{RD} : \mathrm{RD} + \mathrm{SZ}$.

$$\text{and } \mathrm{RK} = \frac{\mathrm{RS} \times \mathrm{RD}}{\mathrm{RD} + \mathrm{SZ}};$$

and substituting for SZ its value, already found, and RO — SO for RS, we have

$$\mathrm{RK} = \frac{(\mathrm{RO} - \mathrm{SO})\mathrm{RD}}{\mathrm{RD} + \frac{n}{d}\mathrm{SO} - \mathrm{MZ}}.$$

When the point D, therefore, approaches to O, and K to F, the focus conjugate to R, we have

$$\mathrm{RK} = \frac{(\mathrm{RO} - \mathrm{SO})\mathrm{RO}}{\mathrm{RO} \times \frac{n}{d}\mathrm{SO}}$$

and consequently the Aberration

$$\mathrm{FK} = \mathrm{RK} - \mathrm{RF} = \mathrm{RO} - \mathrm{SO}\left(\frac{\mathrm{RD}}{\mathrm{RD} + \frac{n}{d}\,\mathrm{SO} - \mathrm{MZ}}\right) - \frac{\mathrm{RO}}{\mathrm{RO} + \frac{n}{d}\mathrm{SO}} = \mathrm{RO} - \mathrm{SO} \times \frac{\left(\mathrm{RO} \times \mathrm{MZ} - \frac{n}{d}\mathrm{SO}\right)(\mathrm{RO} - \mathrm{RD})}{\left(\mathrm{RD} + \frac{n}{d}\mathrm{SO} - \mathrm{MZ}\right)\left(\mathrm{RO} + \frac{n}{d}\mathrm{SO}\right)}$$

With the radius RD describe the arch DE, cutting SO in E, then we have RO — RD = EO, and RD = RO — EO. Hence we have, by substitution,

$$\mathrm{FK} = \frac{(\mathrm{RO} - \mathrm{SO})\left(\overline{\mathrm{RO} \times \mathrm{MZ}} - \frac{n}{d}\overline{\mathrm{SO} \times \mathrm{OE}}\right)}{\left(\mathrm{RO} + \frac{n}{d}\mathrm{SO} - \mathrm{MZ} - \mathrm{OE}\right)\left(\mathrm{RO} + \frac{n}{d}\mathrm{SO}\right)} = \frac{\mathrm{RO} - \mathrm{SO}}{\left(\mathrm{RO} + \frac{n}{d}\mathrm{SO}\right)^2}\left(\overline{\mathrm{RO} \times \mathrm{MZ}} - \frac{n}{d}\mathrm{SO} \times \mathrm{OE}\right),$$

because $\left(\mathrm{RO} + \frac{n}{d}\mathrm{SO}\right)^2$ is very large in comparison with $\left(\mathrm{RO} + \frac{n}{d}\mathrm{SO}\right)$ (MZ + OE.)

But (see Prop. XXVI.) $\mathrm{XO} : \mathrm{XE} = \mathrm{RE} : \mathrm{SO}$, and

By Geom. Prop. VI. $\mathrm{XO} : \mathrm{XO} - \mathrm{XE} = \mathrm{RE} : \mathrm{RE} - \mathrm{SO}.$

Or by substituting RO for RE, to which it is nearly equal, we have

$\mathrm{XO} : \mathrm{EO} = \mathrm{RO} : \mathrm{RO} - \mathrm{SO}.$ Hence

$$\mathrm{EO} = \frac{\mathrm{RO} - \mathrm{SO}}{\mathrm{RO}} \times \mathrm{XO};$$

and by substituting in the general equation the values of EO and MZ, and $m - n$ for d, we obtain finally

$$\text{The Aberration FK} = \left(\frac{\mathrm{RO}-\mathrm{SO}}{\mathrm{RO}+\frac{n}{m-n}\mathrm{SO}}\right)^2 \times \frac{n^2\mathrm{RO} - n^2\mathrm{SO} - m\,n\mathrm{SO}}{\overline{m-n} \times m\,\mathrm{RO}} \times \mathrm{XO}.$$

Cor. 1. In order to obtain an expression of the aberration in terms of the semi-aperture, in place of the thickness of the lens, we have, Euclid vi. 13, $\mathrm{OX} : \mathrm{XD} = \mathrm{XD} : 2\mathrm{OS}$ and $\mathrm{OX} = \frac{\mathrm{XD}^2}{2\mathrm{OS}}$; hence, we obtain

$$\mathrm{FK} = \left(\frac{\mathrm{RO}-\mathrm{SO}}{\mathrm{RO}+\frac{n}{m-n}\mathrm{SO}}\right)^2 \times \frac{n^2\mathrm{RO} - n^2\mathrm{SO} - mn\,\mathrm{SO}}{\overline{m-n} \times (2m\,\mathrm{RO} \times \mathrm{SO})}\mathrm{XD}^2.$$

Cor. 2. When the radius SO becomes infinite, the surface is plane, and hence we have for the aberration of a ray refracted at a plane surface,

$$\mathrm{FK} = \frac{m^2 - n^2}{mn} \times \frac{\mathrm{XD}^2}{2\mathrm{RO}}.$$

Cor. 3. When RO and SO are given, the longitudinal aberration of the outermost refracted ray varies, as XD^2, or as the square of the semi-aperture.

Cor. 4. By considering the change that takes place in the signs of the different quantities, according as the centre of the refracting surface, the conjugate foci, and the radiant point, are on the same or on different sides, we may easily obtain an expression of FK for all kinds of surfaces, and for converging and diverging, and parallel rays.

Cor. 5. The aberration of lenses may be found by the application of the preceding formulæ. After determining the aberration of the first surface, we must consider the focal distance of the second as shifted by the aberration of the first, and then determine the general aberration by the formula.

Scholium.

As our limits will not permit us to treat this subject at any greater length, we must refer to the Optics of Dr. Smith, whom we have followed, after Huygens, in the above propositions, for any farther information he may require. We shall, however, lay before our readers some of the most useful formulæ, the demonstration of which will be found in the works quoted at the end of this scholium.

The following are Dr. Smiths's formulæ for lenses of glass whose index of refraction is 1.5 or $\frac{3}{2}$.

Let P = Thickness of the lens.
R = Radius of the *first* surface.
p = Focal distance of the lens.
r = Radius of the second surface.
D = Difference of thickness of the centre and margin of the lens. Then

1. The longitudinal aberration $= \dfrac{\left.\begin{matrix}-27RR\\ +\ 6Rr\\ -\ 7rr\end{matrix}\right\}PP\left.\begin{matrix}+66RRrr\\ +14Rrr\end{matrix}\right\}P - 52RRrr}{6PP(R-r)^2 - 24PRr(R-r) + 24RRrr}D.$

2. Aberration $= \dfrac{-27RR + 6Rr - 7rr}{6(R-r)^2}D.$ For parallel rays.

3. Aberration $= \dfrac{27RR + 24Rp + 7pp}{6RR}D.$ For parallel rays in terms of R and p, when the centre of the surfaces are both on one side.

4. Aberration $= \dfrac{27RR - 24Rp + 7pp}{6R}D.$ For do. when the centres of the surfaces are on different sides of the lens.

5. Aberration $= \dfrac{7pp + 4rp + rr}{6rr}D.$ For do. in terms of r and p, when the centres of the surfaces are on the same side.

6. Aberration $= \dfrac{7pp - 4rp + rr}{6rr}D.$ For do. when the centres are on opposite sides.

From these formulæ, Huygens and Dr. Smith deduced the following numerical results.

1. For a *plano-convex lens*, with its plane side turned towards parallel rays, as it would be, if placed as an object glass in a telescope, with the plane side outwards, or as it would be if used as a microscope, with the plane side towards the eye, the *aberration* is $= 4\frac{1}{2}$ times its thickness.

2. For a *plano-convex lens*, with its convex side towards parallel rays, as it would be, if placed as an object glass in a telescope, with the convex side outward, or as it would be if used as a microscope, with the convex side next the eye, the aberration is $= 1\frac{17}{100}$ of its thickness. Hence it is always advisable when a plano-convex lens is used, to have the parallel rays either incident or emergent from its convex surface.

3. A *double convex* glass, the radii of whose convexities are as 2 to 5, has the same properties as the plano-convex glass in § 1. if its flattest side, or the side whose radius is 5, is turned to parallel rays; or it has the same property as the plano-convex lens in § 2. if its most convex side, or that whose radius is 2. is turned towards parallel rays.

4. The *lens of least spherical aberration* is one which has its radii as 1 to 6, the side whose radius is 1 being turned to parallel rays. The aberration is then only $1\frac{7}{100}$ of its thickness.

5. When this same lens with radii as 1 to 6, has its flattest side, viz. 6, turned to parallel rays, its aberration is $3\frac{45}{100}$ of its thickness; and is, therefore, very unfit for vision.

6. A double lens with equal convexities or concavities has its aberration, $1\frac{67}{100}$ of its thickness; and is, therefore, inferior to a plano-convex lens, or to the double lens in § 4.

The following formulæ, investigated by Boscovich in his *Opera Pertinentia ad Opticam*, &c. Tom. i. p. 174, relate to the focal length of the lenses placed together, viz. a convex and concave one of different refractive powers, and will be of great use in all calculations respecting achromatic combinations.

$a, b, c, d,$ = The radii of the four spherical surfaces.
$e,$ = Radius or semidiameter of the aperture of the lens.
$\alpha, \gamma,$ = Thickness of the first and second lenses.
$\beta,$ = Interval between the lenses.
$m : 1$, $M : 1$ = The ratios of refraction in the two kinds of glass.
p = Distance of the radiating point, or of the object.
q, r, Q, R = Focal distance of rays infinitely near the axis, neglecting the intervals between the surfaces.
h, H = Focal distances of parallel rays infinitely near the axis for the first and second lenses respectively, neglecting the intervals between the surfaces.

$$\frac{1}{f} = \frac{1}{a} - \frac{1}{b};\quad \frac{1}{g} = \frac{1}{c} - \frac{1}{a}.$$

$$\frac{1}{f} = \frac{m-1}{m\,a} + \frac{1}{m\,p}$$

$$\frac{1}{q} = \frac{m-1}{f} + \frac{1}{p} = \frac{1}{p} + \frac{1}{p}.$$

$$\frac{1}{Q} = \frac{M-1}{M\,c} + \frac{1}{M\,r} = \frac{M-1}{M\,c} + \frac{m-1}{M\,f} + \frac{1}{M\,p}.$$

$$\frac{1}{R} = \frac{M-1}{g} + \frac{1}{r} = \frac{M-1}{g} + \frac{m-1}{f} + \frac{1}{p} = \frac{1}{H} + \frac{1}{h} + \frac{1}{p}.$$

$$\varrho = \frac{m-1}{m}\left(\frac{m^3}{f^3} - \frac{2m^2+m}{af^2} + \frac{m+2}{a^2f} + \frac{3m^2+m}{pf^2} - \frac{4m+4}{apf} + \frac{3m+2}{p^2f}\right)\frac{1}{2}e^2.$$

$$\sigma = \frac{M-1}{M}\left(\frac{M^3}{g^3} - \frac{2M2+M}{cg^2} + \frac{M+2}{c^2g} + \frac{3M+M}{rg^2} + \frac{4M+4}{crg} + \frac{3M+2}{r^2g}\right)\tfrac{1}{2}e^2.$$

Focal distance of the first lens $= r - r^2 \times \frac{m\,\alpha}{q^2} - r^2\,\varrho.$

Focal distance of both lenses together $= R - R^2\left(\frac{m\,\alpha}{q^2} + \frac{\beta}{r^2} + \frac{M\,\gamma}{Q^2}\right) - R^2\,(\varrho \times \sigma).$

The last but one of these formulæ consists of three parts, viz. r, or the focal length of an infinitely slender pencil of rays, $r^2 \times \frac{m\alpha}{q^2}$ the correction for the thickness of the lens, and $r^2\,\varrho$ the spherical aberration.

The last formula also consists of three terms, viz. R, or the focal distance of a slender pencil of rays refracted by both lenses, their thickness and their distance being neglected; then $-R^2\left(\frac{m\alpha}{q^2} + \frac{\beta}{r^2} + \frac{M\gamma}{Q^2}\right)$ is the correction for the thickness and distance of the lenses, and $R^2 - (\varrho + \sigma)$ the correction for the aberration.

Dr. Maskelyne has given a very useful formula for the aberration of a lens, which we shall here explain. He assumed the form of the lens to be a meniscus, the radius of whose convex surface is greater than that of its concave surface, and, consequently, having the centres of both lying on the same side of the lens as the radiant point upon which the incident rays diverged. The ray which falls from the extreme part of the lens will, after refraction, diverge from a point before the lens, nearer to it than the geometrical focus of rays diverging from the same radiant point, and passing indefinitely nearer the vertex. In the following formulæ,

Q = the distance of the radiant point, before the lens from its vertex.
R = the radius of concavity of the first surface.
r = radius of convexity of the second surface.
F = principal focus, which will be on the same side of the lens as the radiant point, because R is less than r.
Y = the semi-aperture of the lens; and
$m : n$ = ratio of the sines of incidence and refraction.

Then the angular aberration of the ray falling on the margin of the lens, or the angle made between this ray, after being refracted through the extremity of the lens, and another ray or line supposed to be drawn from the same extremity of the lens to the geometrical focus of rays diverging from the same radiant point, and passing indefinitely near the vertex of the lens, expressed in measures of the arc of a circle, the radius unity will be

$$\text{Aberration} = \frac{(m^3 - 2m^2n + 2n^3)Y^3}{(m-n)^2 \times 2m \times F^3} + \frac{(mn + 4n^2 - 2m^2)Y^3}{(m-n) \times 2m \times F^2 r} + \frac{(m+2n)Y^3}{2m \times F r^2} - \frac{(4n^2 + 3mn - 3m^2)Y^3}{(m-r) \times 2m \times QF^2} - \frac{(2m+2n)Y^3}{m \times QFr} + \frac{(3m+2n)Y^3}{2m \times Q^2F}.$$

In this formula, R, the radius of the first surface, is exterminated, and r, the radius of the second, retained. If we exterminate r, and retain R, the angular aberration will be

$$\text{Aberration} = \frac{m^2 \times \mathrm{Y}^3}{(m-n)^2 \times 2\,\mathrm{F}^3} - \frac{(2\,m+n)\mathrm{Y}^3}{(m-n)\times 2\,\mathrm{F}^2\mathrm{R}} + \frac{(m+2\,n)\mathrm{Y}^3}{2\,m \times \mathrm{FR}^2} + \frac{(3+n)\,\mathrm{Y}^3}{(m-n)2\mathrm{QF}^2} - \frac{(2\,m+2\,n)\,\mathrm{Y}^3}{m \times \mathrm{FQR}} + \frac{(3\,m+2\,n)\,\mathrm{Y}^3}{2\,m \times \mathrm{Q}^2\mathrm{F}}.$$

In order to adapt the formula to those cases where the principal focus lies behind the glass, F must be taken negative. When the rays fall converging on the lens, Q must be taken negative. If the first surface is convex, R must be taken negative; and if the second surface be concave, r must be taken negative. If, after all these circumstances are taken into account, the value of the aberration comes out positive, it will make the focus of the extreme rays fall nearer the lens before it than the geometrical focus, or farther from the lens behind it; but if the value of the aberration comes out negative, it will cause the focus of the extreme rays to fall farther from the lens before it than its geometrical focus.

The following formulæ are given by Boscovich for determining the relative radii of the sphericities that give a minimum aberration, a being the radius of the first surface, or that next the incident parallel rays, and b the radius of the second surface.

$$\frac{1}{a} = \frac{2\,m^2+m}{2\,m+4} \text{ for Parallel rays.}$$

$$\frac{1}{b} = \frac{2\,m^2+m}{2\,m+4} + \frac{4\,m+4}{2\,m+4} \text{ for Converging and Diverging rays.}$$

$$\frac{1}{b} = \frac{1}{a} - 1.$$

When $m = \frac{3}{2}$, or 1.50 $a : b = 1 : -6$.
When m = 1.52 $a : b = 1$ —6.83
When m = 1.53 $a : b = 1 : -7.33$
When m = 1.54 $a : b = 1 : -7.89$

In order to convey an accurate idea of the effect of aberration, Boscovich has computed a table for three different kinds of crown or plate glass, and suited to the two species of lenses which are of most use in eye-glasses, viz. for those which receive parallel rays, and those which receive rays converging to their principal focus.

Index of refraction, or m = . .	1.50	1.52	1.54
Radii of Sphericities that give a Minimum Aberration, the Focal Length being 1.			
a b	0.5833 —3.5	0.5961 —0.4072	0.6085 —0.4800
a' b'	0.3182 0.875	0.3216 0.8431	0.3248 0.8152
Ratio of the Radii that give a Minimum Aberration.			
$a : b$ $a' : b'$	1 : —6. 1 : 2.75	1 :—6.831 1 : 2.621	1 :—7.889 1 : 2.510

Errors in Lenses of different kinds.			
Error in lens that gives the minimum aberration.	0.267 0.0040	0.274 0.039	0.280 0.038
Plano-convex lens, plane side turned to the eye .	0.291 0.135	0.293 0.149	0.295 0.161
Double isosceles convex lens	0.416 0.375	0.434 0.400	0.455 0.427
Plano-convex lens, plane side turned to the object	1.125 0.760	1.155 0.796	1.186 0.833

For farther information on the subject of spherical aberration, see Hugenii *Dioptrica*, p. 88, and prop. xxvii. and xxviii. Barrow's *Lectiones Opticæ*. Newton's *Lectiones Opticæ*, prop. xxxvii. part i. sect. iv. p. 148. Smith's *Optics*, vol. i. p. 134. 252. Klingenstierna, *Phil. Trans.* 1760, p. 944. Maskelyne, *Phil. Trans.* 1761, p. 17. Kaestner, *Comment. Gotting.* i. p. 185. ii. p. 183. Euleri *Dioptrica*, vol. i. Boscovich, *Opera Pertinentia ad Opticam*, &c. vol. ii. p. 128, &c. Wood's *Optics*, p. 195; and Robison's *System of Mechanical Philosophy*, vol. iii. p. 409.

Before we conclude this section, we shall consider the manner in which the light is distributed in the circle of aberration, whose radius is $x\,y$, Fig. 7. Every point of an image formed by a spherical lens is represented by this little circle, and an indistinctness must arise from the interference and crossings of all these expanded elementary images. Sir Isaac Newton, who seems to have first investigated this point, supposes that the light is much more dense at the centre than at the circumference; and he therefore concluded that the error from the spherical figure was much less than it really is. This oversight of our illustrious countryman was first pointed out by the Abbé Boscovich, in a dissertation published at Vienna in 1767; and he afterwards resumed and completed the inquiry, in his *Opera Pertinentia ad Opticam et Astronomicam*.

Def. A *Caustic* is a curve formed by the intersection of a great number of rays of light, and as the space of aberration or diffusion is bounded by an infinite number of rays of light advancing to different points of the axis, and therefore crossing one another, the bounding line will be a caustic.

Prop. XXX.

To determine generally the distribution of the light in the circle of diffusion, produced by the spherical aberration of a refracting surface.

Let FAF′, Fig. 9. be the lens or refracting surface, B the point of intersection, or focus of the two marginal rays, FBC′, F′B,C, and I the point of intersection of the rays near the centre, such as ABI. The foci of all the rays will therefore be contained in the the line IB; COC′ will be the diameter of the circle of diffusion, and DCI, D′C′I′, will be the two caustic curves formed by the contact or intersections of all the rays that cross the axis between B and I.

These caustics, in the parts which are infinitely near the axis at I, approach infinitely to the parabola of the third degree, which has the squares of its ordinates TN, (Fig. 10,) as the cubes of the abscissæ IN. The arch DID of Fig. 9. may be considered as a curve of this kind.* The subtangent LN is to the abscissæ IN as 2 to 3;—EB is $\frac{2}{3}$ IF; BO$=\frac{1}{4}$ BI, and consequently the diameter of the aperture FF′, which is to the diameter of the circle of diffusion CC′ as AB supposed equal to AI, is to BO, will be as 4 to 1.

From the centre O of the circle of diffusion there can obviously be drawn two rays or lines, OV, OV′ touching the caustics in V and V′. The point O will therefore receive the ray AO passing through the vertex of the refracting surface, and likewise all the rays which pass through the circumference of a circle described on the refracting surface by the extremity of the ray OV, or OV′, and therefore *the density of the light will be indefinitely great in the centre of the circle of diffusion.*

In like manner we may conceive that there may be drawn from the point C or C′, in the circumference of the circle of diffusion, only two lines or rays, CD, CD′, one of them touching the caustic in D, and the other in D′ on the opposite side. The rays which touch the caustic in the immediate vicinity of C, both in the arches CV and CI, will cut OC in points indefinitely near each other; for their distance on the line OC′ will be to their distance on the refracting surface FF′, as the interval between their points of contact with the caustic, is to the distance of those points from the refracting surface FF′. Although, therefore, only two rays can arrive at the point C, C′, yet a great number pass infinitely near to it, and consequently *in the circumference of the circle of diffusion, the density of the light will be indefinitely great.*

In order to obtain distinct conceptions of the manner in which the distribution of the light takes place, let us conceive a thread fixed at the point I, and lapped up against the convex surface of the caustic DCI, and after being gradually unlapped, again lapped up against the curved surface of the other caustic D′ C′ I; or, in some cases, it will be better to conceive the straight edge of a ruler laid against the convex surface DCI, and rolled, as it were, upon it, so that the point of contact of the ruler and of the caustic may move along the whole caustic. Let us now suppose that the edge of the ruler is brought into contact with the straight line FD, touching the refracting surface at F, and the caustic at D, the part of it DC′, which diverges from the caustic, will cut C′OC in the point C′. Let the ruler now revolve so that its extremity at F passes over the space FA, its point of contact with the caustic, which was at first at D, will move gradually along the branch DV of the caustic; and when it arrives at V, the extremity of it will be at Y, on the refracting surface, and the intersection of the edge of it with C′ C′ will be at O†. As the motion of the ruler continues, the point of contact will move from V to Z, and the extremity of it from Y to Q on the refracting surface; and the intersection of its edge with C′C will be at q, so that $Oq^2 = \frac{OC^2}{2}$. The point of contact, will next move from Z to C, the extremity of the ruler from Q to Y on the refracting surface, and the intersection of the edge from q to C.—While the point of contact continues to advance from C to I, the extremity of the ruler will move from X to A, and the intersection of the edge with C′C will move backwards from C to O.

The ruler being now applied to the other caustic, IC′D′ the point of contact commencing with I, the very same effects which we have now enumerated, will take place only in a retrograde order. Thus,

When the contact is at C′, the extremity is at X′, and the edge at C′
When the contact is at Z′, the extremity is at Q′, and the edge at q'
When the contact is at V′, the extremity is at V′, and the edge at O
When the contact is at D′, the extremity is at F′, and the edge at C.

In this manner the extremity of the ruler has passed over the whole refracting surface FE′, the point of contact descending from D down the curve DVZCI, and again ascending the curve IC′Z′V′D′, while the intersection of its edge with the line C′C has passed from C′ to C; back again from C to C′, and then back again from C′ to C, where it stops, having thrice passed through every intermediate point of C′C. Now every one of the infinite number of positions of the edge of the ruler while its extremity passes from F to F′, may be considered as one of the infinite number of rays which are refracted by the surface of the lens FF′. Hence it is obvious that the edge of the ruler passes only twice through the points C C′, and three times through any point intermediate between C and C′, and therefore only two rays can possibly arrive at the points C C′, while *three* only can arrive at any intermediate point, excepting at the centre O, where only two in a given plane can arrive, but an infinite number from the circumference of a circle described on the refracting surface, as already mentioned.

In order to determine the density of the light in different points H of the circle whose diameter is CC′, let us conceive a ray ph infinitely near PH, the point of whose intersection with the caustic may be assumed at T, the same as that for PH. The density of the rays in the small elementary space H h will be to their density in the corresponding elementary space P p on the refracting surface, as the annulus P p is to the annulus H h. But the area of the former is to the area of the latter in the compound ratio of their breadths Pp, Hh, and of the circumference of a circle whose radius is AP, to the circumference of a circle whose radius is OH. The first of these ratios is that of PT : TH or AN : NO ; and the second ratio that of AP to OH, or AL to OL. Consequently these ratios, when compounded, will be that of AN × AL to NO × OL. But on account of the great distance of A from the points N and L, nearest to I, AN and AL may be both reckoned equal to the constant quantity AI ; and therefore since the density of the light in the annulus Pp, or that of the incident rays, is constantly the same throughout the whole aperture, the density in H will be reciprocally as the rectangle NO×OL, or as SN is triple of ON by the property of the caustic already mentioned, we have the density at H reciprocally as ON×NS.

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* The figure is quite out of proportion, the caustic curves being magnified very much in relation to the focal length AI, in order to show the contacts and intersections of the lines.

† The line YO, and also the lines Q q, XC, are not completely drawn in the Figure, lest it should become too complicated, and more important lines be obliterated.

This variation in the density of light may be well represented by the following construction. Upon the line OS, as a diameter, describe the circle SsO ; through N draw Ns perpendicular to SO, and cutting the circumference of the circle in s. Then we have (GEOMETRY, Prop. XXVIII.) $Ns^2 = ON \times NS$, and consequently the density at H will be reciprocally as Ns^2. Hence we have the following rule for estimating the density at any point. From the point where any ray touches the caustic, such as T, draw a line TN to the axis, and continue this to the circumference s; the density will vary as Ns^2, or joining Rs, and drawing Rβ perpendicular to NS, let fall from β the line βo perpendicular to Ns, and meeting sR prolonged in o; then so will vary as $\frac{1}{sN^2}$ that is, the density of the light will vary as so.

Let us now suppose that the point H coincides with O ; in this case N will coincide with S, and so will be infinite. While H moves from O to C, the point N will approach to R, and so diminish till H comes to q, and T to Z, and s to σ, and o to R. When H moves from q towards C, the point T passes Z, and so again increases till it becomes infinite, when H reaches the point C ; T the point C ; and N the point O .*

Hence it follows, in general, *that the density of the light in the circle of diffusion is infinite at its centre. From this point, it diminishes to a point, the square of whose distance is equal to half the square of the radius. It then increases again, till at the circumference it becomes infinite a second time. At the point where it is a minimum, its density is so strong as to be equal to the density that it would have had, if the light had been equally distributed over the whole circle of diffusion.*

From these results, it appears, that the indistinctness arising from spherical figure is much greater than Newton had supposed; and that the correction of colour, even in the most perfect manner, would still have left the refracting telescope with many imperfections, had not the combination of surfaces enabled the optician to correct the spherical aberration along with that of colour.

In the present improved state therefore, of optical instruments, we must on no account abandon the hope of still removing from single lenses, or, at least, diminishing the amount of, their spherical aberration, especially after means have been taken to remove, by the use of homogeneous light, all the errors of the different refrangibility of light.

PROP. XXX.

To determine the shape and properties of caustic curves formed by refraction.

Having already seen, that rays incident upon a refracting surface or lens are collected at, or converge to, different points in the axis of the refracting body, it is manifest that the rays must intersect one another before they reach the axis;—that these points of intersection will lie in curve lines called caustics;—and that the nature of these will vary with the aperture of the lens and with the position of the radiant point.

If we expose a globe of glass or water to the rays of the sun, or to those of a candle, and receive the refracted rays upon a piece of white paper, held, as nearly as can be, parallel to the axis of the beam of light; we shall observe, that the luminous figure on the paper is bounded by two bright caustics, which, as their distance from the globe increases, gradually approach towards one another, and to the axis of the lens, where they meet, forming a sharp cusp or angle, the point of which is the focus of the rays. Upon examining these curves, it will be seen that they are formed by the intersections of any ray with the adjacent one taken in their order of succession, from one side of the globe to the other. The brightness of the paper within the curves, is therefore produced by a number of intersections of rays within, and the darkness of the paper without the curves, from there being there no intersections at all.

In Fig. 11. let Q be a candle, or a radiant point of any kind, ABC a refracting globe, whose centre is F, and let a divergent beam of light issuing from Q fall upon its anterior surface. Now the rays Q 0, Q 1, will form an intersection at q, the conjugate focus to Q. The rays Q 1, Q 2, will form another intersection at 1 ; the rays Q 3, Q 4, another at 2 ; and the rays Q 5, Q 6, at 6 ; and the same will take place with the rays on the other side of the axis QE q.

When the radiant point Q approaches to the sphere, the conjugate focus q will recede from it ; and when Q comes near F, the anterior focus of the sphere, the rays nearest the axis will first become parallel, then those a little distance from the axis, and so on ; and while those near the axis are parallel, those remoter from it will form intersections with the parallel ones ; and corresponding rays on each side will form intersections and partial foci without number along the axis of the sphere.

This effect will be understood from Fig. 12. where the radiant point Q is coincident with the anterior focus F. The rays Q 1, 1, infinitely near the axis, are of course parallel, as shown in the figure at 1 q, 1 q. The rays Q 2, Q 2 at a greater distance from the axis will form intersections at 1, 1, with the rays Q 1, Q 1, while the corresponding ones on opposite sides of the axis will form intersections with one another, and with the central ray at 2 q ; and the rays, Q 3, Q 3, will also form intersections at 3 q.

When the point Q is a little within F, the rays Q 1, Q 1, will become divergent, and will have their negative or virtual intersection in front of the sphere, and to the right of F, while the rays Q 2, Q 2, will now be parallel to the axes, and Q 3, Q 3, will be convergent to a positive focus in the axis of the lens. Hence we have the paradoxical result, that the same sphere will *diverge* rays incident near its axis from a given radiant point; will *render parallel* rays from the same radiant point, but incident more remote from the axis; and will *converge* rays from the same radiant point, but incident at a greater distance from the axis.

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* These conclusions may be deduced with equal facility, merely by considering the change which takes place in the rectangle ON×NS, by making the point N move along the line S O.

When Q approaches very near the sphere, the intersections of all the rays fall in front of it, and caustics are formed, diverging from a point near its anterior focus, and away from the sphere.

In order to form an idea of the shapes of causticd curves, we must consider some of their modes of formation.

1. Let EBE, Fig. 13. be a convex refracting surface terminating a dense medium, A its focus, and C its centre. Upon A as a centre, and with the radius AC, describe the circle DCD, and draw the equal chords CD CD, so that CD : CB=Sin. Incid : Sin. Refract. Then, if we draw the incident rays EDE, EDE, the caustic will commence at the points E, E, and will approach the axis AF, till it meets it at the principal focus F, where it will form a cusp or sharp point, provided AB exceed the focal length of the refracting surface.

2. When CA : CB=Sin. Incidence : Sin. Refraction; then, by Prop. xviii. the caustic will be contracted into a single point F, from which all the rays will diverge.

3. When the parallel rays AB, AB, Fig. 14. fall upon the plane side of a plano-convex lens, and are refracted only at its spherical surface BB, the position of the refracted rays is determined in the same manner as in the following case.

4. Let us suppose the radiant point A, Fig. 15. to be the rarer medium, and C the centre of the refracting surface in the denser; then having drawn the tangents AD, AD to the circle DBD, join CD, CD, upon them as diameters, describe the semicircles CED, CED, towards the denser medium, and take lines, CE, CE, so that CE : CD=Sin. Refraction : Sin. Incidence, and the legs of the caustic will begin from the points E, E, in the direction DE, DE.

Some of the most interesting phenomena of caustic curves may be illustrated experimentally by covering one side of a globe, or of a large convex lens, with a circle of dark paper, the diameter of which has a row of small holes made in it with a pin, at equal distances from one another. When a piece of white paper is held close behind the globe or lens, and perpendicular to its axis, the spots of light formed by the holes will appear on the paper at equal distances from one another; but when the paper is withdrawn from the globe or lens, the interval between the exterior spots will grow less than that between the interior ones, and will unite at the points of intersection. With a deep concave lens, on the contrary, the interval between the interior spots will grow less than that between the exterior ones, in consequence of the exterior rays diverging from points nearer the lens than those from which the interior rays issue.

For farther information on the subject of caustics by refraction, see Smith's *Optics*, vol. i. p. 21, 1791; and Huygens, *Traité de la Lumiere*, p. 119.

Sect. VIII.—*On the Theory of the Refraction of Light.*

Having found, from various optical facts, that light exhibited the appearance of being attracted and repelled by bodies near which it passed, Sir Isaac Newton concluded, that the phenomena of refraction were produced by an attractive power residing in all bodies, and extending to some distance beyond their surfaces. He has also shown that this power is infinitely stronger than the force of gravity. As all bodies attract one another by the force of gravitation, he has demonstrated that the attractive forces of two homogeneous spheres upon particles of matter, placed near their surfaces, are in the ratio of the diameters of the spheres *. If a refracting medium, for example, of the same density as the earth, be spherical, the attractive force exerted by the earth near its surface will surpass that of the medium near its surface, as much as the diameter of the earth surpasses the diameter of the medium, or almost infinitely. When we consider, however, that a ball impelled from the mouth of a cannon is at first scarcely deflected towards the earth in virtue of its attraction, and that gravity acts upon all bodies alike, it follows, that the least particle of the ball, if separated from the rest of the mass, would be no more deflected than the whole. Hence, it follows, that a particle of light which moves with an infinitely greater velocity than a cannon ball, would be much less deflected from its path by the attractive force of the whole earth, and therefore infinitely less by the attractive force of the medium, as it is infinitely weaker than that of the earth. But as the ray of light is actually deflected from its path, or refracted in a very considerable degree by the small spherical medium, it follows, that it must be acted upon by some other power residing in the medium, than its force of gravity; and that this power must be infinitely stronger near the surface of the medium than the force of gravity. From whatever cause this power of refracting light is derived, we may call it the refracting force, although the law of its action is still unknown. As it is, however infinitely stronger than gravity at the surface of bodies, and is imperceptible at very minute distances from them, there is reason to suppose that it decreases more rapidly, or in a much greater ratio, than the force of gravity.

The refracting force of a homogeneous medium acts upon light in directions parallel to the refracting surface; that is, in every point of a plane drawn parallel to the refracting surface, it will be equally strong, though in the next succeeding plane, its force may be different. The extent of the refracting force will therefore be bounded by two planes parallel to one another and to the refracting surface, and the space between them has been called the *space of activity*, whether the power which resides within it is exerted in attracting or repelling the incident light.

In order to show that the refracting force will act upon light in lines or directions perpendicular to its surface, let ABCD, Fig. 16. be the refracting medium, and let a particle of light P be acted upon by any uniform power in the line $o\,p$ parallel to the surface of the medium, and $P\,q$ a line drawn from P, perpendicular to $o\,p$. Then the refracting power exerted at any point, q will draw the particle P in the direction $P\,q$, and taking any two points, c, d, equidistant from q, it is obvious that the refracting forces at c and d being of equal intensity, and acting at equal angles upon the particle P, will draw P likewise in the direction P q; and as the same is true of equal forces in all lines within the space of activity parallel to the refracting surface, it follows, that by the refractive force of every part of the refracting medium, the particle P will be acted upon in directions perpendicular to the surface of the medium. The velocity of the particle P will obviously be increased or diminished according as the force of the medium acts in the direction of its motion, or in an opposite direction, and when the particles have passed through the space of activity, they will move through the medium with the velocity which they had acquired when they quitted it.

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* *Principia*, Lib. i. Prop. 71. Cor. 2. and Lib. iii. Prop. 8.

When a ray of light RP falls obliquely upon the space of activity $o\ p\ m\ n$ of a refracting medium ABCD, as in Fig. 17. the refracting force will now act obliquely upon its particles, and will bend the ray into a curve P $q\ r$ in the same manner as all other bodies are deflected from their path by the action of any attracting medium. After the ray has entered the surface of the medium at q, it will still be attracted to the medium, till it arrives at the point r, for till it reaches the line mn, there will not be so many particles above it, which will attract it upwards, as there are particles below it, that will attract it downwards; so that, after it has penetrated the surface AB at q, in the direction P q, it will not proceed in that direction, but will continue to describe a curve as $q\ r$. As soon, however, as it quits the space of activity at r, it will advance forward in a straight line r S with the velocity which it has acquired, as it is now equally attracted on all sides.

When a ray passes out of a denser into a rarer medium, the same effects take place, but with some modifications. If the ray falls perpendicularly upon the surface of the rarer medium, its velocity is diminished in passing through the space of activity. But if its direction is oblique, as in Fig. 2. the ray S r is constantly bent from the perpendicular, and its deflection continues till the ray escapes at P into the rarer medium.

If the obliquity of the ray, however, is greater than that of S r in Fig. 2. and like that of RP in Fig. 18, the ray will go on to q, bending from the perpendicular, and when it reaches q, it will be so much acted upon by the refracting force, that, instead of advancing through the remaining portion of the space of activity, it will actually be turned backward in the direction $q\ r$, and, as it were, reflected in the direction r S. In this case the refraction of the ray is performed in the same manner as if a stone were projected in the direction RP, and made to describe a curvilineal path P $q\ r$ by the force of gravity. If we suppose the attraction of the earth to extend no higher than the line $o\ p$ in Fig. 2. then the stone escaping from its influence at P, would move on in a straight line PR. But we may conceive the force of projection so weak, or the gravity of the stone so great, or the direction of its path so oblique to the horizontal line $o\ p$, Fig. 3. that it cannot ascend so high as this line. The stone will consequently descend from the highest point of its path, viz. q, by the same degrees of deflection with which it ascended, that is, in a curve qr similar to P q, and if the gravitating force is supposed to cease at all points below $m\ n$, the stone will advance onward in the direction r S of the last portion of the curve. The ray may even emerge from the medium, as shown by R$'c$S$'$, and still be reflected back into it, provided the highest point of its passage, viz. c, is not without the boundary $o\ p$ of the space of refracting activity.

Hitherto we have supposed that the ray passes from a vacuum into the refracting medium, or *vice versa*, but the very same effects will be produced, though in a different degree, when the ray passes from one medium into another of different density. The ray will, in this case, not be so much refracted from its rectilineal direction; for, since the attraction of the particles of the upper medium is exerted in a direction contrary to that of the lower medium, the attraction of the denser medium will be in some measure destroyed by that of the rarer, the light being affected only by the difference or resultant of the forces with which it is influenced. If the two media act upon light with equal forces, their opposite actions will destroy one another, and the ray will pass from the one into the other without changing either its velocity or its direction.

As the distance between the limits $o\ p$, $m\ n$ of the space of activity is exceedingly small, even in bodies of the highest refractive power, the curved portion P $q\ r$ of the path of the ray is always neglected in optical discussions, and the refraction is supposed to be performed at a point in the surface of the refracting medium.

Although we have already shown, from direct experiments, that in all refractions the sine of the angle of incidence bears a constant proportion to the sine of the angle of refraction, yet it is interesting to see how this fundamental truth, on which the whole science of dioptrics is founded, is a necessary consequence of the Newtonian theory of refraction which we have now explained.

Prop. XXXI.

When light is refracted by transparent media, the sine of the angle of incidence is to the sine of the angle of refraction in a constant ratio.

In demonstrating this proposition, Sir Isaac Newton supposes only that bodies refract light by acting on its rays in lines perpendicular to their surfaces. He distinguishes the motion of every ray into two motions, the one perpendicular to the refracting surface, and the other parallel to it;—and he lays down the following preliminary proposition, concerning the perpendicular motion of any body moving with any velocity on any broad and thin space, terminated on both sides by two parallel planes, and in its passage through that space urged perpendicularly towards the farther plane, by any force which, at given distances from the plane, is of given quantities. The perpendicular velocity of that body, emerging out of that space, will be always equal to the square root of the sum of the square of the perpendicular velocity of that body at its incidence on that space, and of the square of the perpendicular velocity which that body would have at its emergence, if at its incidence its perpendicular velocity was infinitely little. If the body is perpendicularly retarded, the same proposition is true; but instead of the sum of the two squares we must take their difference.*

Let a ray RC incident very obliquely on the refracting surface RS at C, be refracted into the line C e;

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* See the *Principia*, Lib. i. Prop. xxxix. and Newton's *Optics*, Book i. Prop. vi. p 68.

and if it is required to find the line CE, into which any other ray, as AC, shall be refracted, let RC, AD be the sines of incidence of the two rays, and EF, ef their sines of refraction. Let the equal motion of the incident rays be represented by the equal lines RC and AC. As the motion RC is parallel to the refracting plane, the other motion AC may be resolved into two motions AD and AC, of which AD is parallel, and DC perpendicular to the refracting surface. In like manner, let the motions C e, CE of the refracted rays be resolved into two motions, one parallel and the other perpendicular to the refracting plane. The perpendicular motion of the ray RC will be $\frac{\mathrm{RC}}{ef}\,\mathrm{C}f$, and that of the ray AC will be $\frac{\mathrm{AD}}{\mathrm{EF}}\,\mathrm{CF}$. Now, if the force of the refracting surface begins to act upon the rays, either at that surface, or at a certain distance from it on the one side, and terminates at a certain distance from it on the other side; and if, in all places within these two limits, or within the space of activity, as above explained, it acts upon the rays in lines perpendicular to the refracting surface, and the action upon the rays at equal distances from the refracting surface be equal, and at unequal distances either equal or unequal, in any ratio whatever;—then the motion of the ray which is parallel to the refracting surface will suffer no change by that force, but the motion which is perpendicular to it will be altered according to the rule above stated.

If we then represent by $\frac{\mathrm{RC}}{ef}\,\mathrm{C}f$ the perpendicular velocity of the refracted ray C e, then the perpendicular velocity of any other ray AC, which was $\frac{\mathrm{AD}}{\mathrm{EF}}\,\mathrm{C}f$, will be altered by the above rule so as to become $\sqrt{\mathrm{CD}^2+\frac{\mathrm{RC}^2}{ef^2}\,\mathrm{CF}^2}$; that is, $\left(\frac{\mathrm{AD}}{\mathrm{EF}}\mathrm{CF}\right)^2=\mathrm{CD}^2+\frac{\mathrm{RC}^2}{ef^2}\,\mathrm{CF}^2$. By adding to each side of the equation the equal quantities AD^2 and $\mathrm{RC}^2-\mathrm{CD}^2$, and then dividing each side by the equal quantities, $\mathrm{C}f^2+ef^2$ and $\mathrm{CE}^2+\mathrm{EF}^2$, we shall have $\frac{\mathrm{AD}^2}{\mathrm{EF}}=\frac{\mathrm{RC}^2}{ef^2}$, that is, $\mathrm{AD}:\mathrm{EF}=\mathrm{RC}:ef$; that is, *the Sine of Incidence is to the Sine of Refraction in a given ratio.*

Cor. 1. When light is incident from a rarer upon a denser medium, and therefore refracted to the perpendicular, its velocity is increased; and when it is refracted from the perpendicular as it is passing out of a denser into a rarer medium, its velocity is diminished. In the first case, therefore, we must consider it as having received this increase of velocity from forces conspiring more or less with the direction of its motion, that is, from an attractive force; and, in the second case, that it has been acted upon by forces acting in opposition to the direction of its motion, that is, by an attracting force drawing it backwards to the refracting medium from which it is emerging.

Cor. As the change produced upon the square of the velocity of light incident upon a refracting surface is a constant quantity, the refraction will diminish as the velocity of the incident light increases.

Having thus explained, as briefly as possible, the Newtonian theory of the refraction of light, it would be improper to quit this subject without endeavouring to convey to the reader some idea of the theory of refraction, which is adopted by those philosophers, particularly Huygens, who suppose that light consists in the undulations of an elastic ethereal medium. The strong arguments by which the Newtonian theory has been so long sustained, have been much weakened by recent discoveries; and the Huygenian system can now boast of being supported by philosophers of the most distinguished eminence, and by arguments which have not yet received any satisfactory reply from the adherents of the Newtonian hypothesis.

According to Huygens, light consists in the undulations of a highly elastic and subtle fluid pervading all bodies, which are propagated round the luminous centre in spherical waves, as represented in Fig. 1. which shows the general manner in which they issue from every point of a candle. Each point, A, B, C, for example, propagates around itself as a centre a series of concentric waves, which intersect one another without producing any confusion. In these undulations the particles of the ether, though in continual motion, are not themselves carried along, but receive only such an impulse that they necessarily communicate it to those around them in the same manner as sound is propagated through air. But while each particle of the ethereal matter in which a luminous wave is propagated, communicates its motion to the next particle in the straight line drawn through the luminous source, it also necessarily communicates a portion of its motion to all the other particles which touch it, and oppose its motion. Hence it follows that each particle will create round it a new spherical undulation, of which it is the centre. Consequently if DCF, Fig. 2. is a wave propagated from the luminous point A as its centre, any particle B within the sphere DCEF will propagate round it its *particular* wave KCL, and the particle G, its particular wave LEF, which will touch the wave DCEF at C and E, at the same moment that the principal wave DCEF, propagated from the point A, arrives in DCF. Hence it is manifest that it is only the point C of the wave KCL which will touch the wave DCEF, viz. the point which is in the straight line drawn through AB. In like manner the other particles within the sphere DCEF, such as b, b, b, b; d, d, d, d, will have each propagated its wave round itself. But each of these particular waves must be infinitely weak, when compared with the wave DCEF, to the composition of which all the others contribute by the part of their surface which is most remote from the centre A. The wave DCEF is determined by the extremity of the motion which issues from the point A in a certain space of time, having no motion beyond this wave, though there is motion in the space which it incloses, viz. in the parts of the particular waves, which parts do not touch the sphere DCEF.

Each part of a wave ought to propagate itself in such a manner, that the extremities are always comprehended between the same straight lines drawn from the luminous point A. Thus the part of a wave BG having for its centre the luminous point A, will propagate itself in the arch CE, terminated by the straight lines ABC, AGE. For though the particular waves produced by the particles contained in the space CAE, also spread themselves out of this space, yet they do not concur at the same instant to compose together a wave which terminates the motion excepting in the circumference CE, which is their common tangent. Hence we see the reason why light, considered as the result of undulations, is propagated only in straight lines; for if we suppose BG an aperture bounded by opaque bodies BH, GI, the wave of light propagated from the point A will be always terminated by the straight lines AC, AF, as has been shown, the parts of the particular waves which extend without the space ACE, too feeble to produce light. Hence, in this theory, we may consider light as propagated in straight lines.

In order to explain the phenomena of refraction, Huygens shows that there are *three* ways in which the undulations constituting light may propagate it through bodies. 1. If the ethereal matter does not penetrate bodies, he supposes that the particles of water, glass, &c. may communicate to one another the motion impressed upon them by the ethereal undulations. 2. He supposes, what he considers most probable, that the ethereal matter occupies the interstices and pores of all transparent bodies. 3. He supposes that the motion of the luminous waves may be transmitted indifferently through the particles of the ethereal matter contained in transparent bodies, or through the particles of the bodies themselves, so that the motion passes from the one to the other.

Upon these data Huygens proceeds in the following manner to explain the principal phenomena of refraction. Let AB represent a plane surface separating two transparent media, and AC a part of a wave of light, whose centre is so remote, that the part AC of the wave may be considered as a straight line. The part C of this wave will in a certain space of time reach the refracting surface AB, in the direction CB, which, as it comes from the luminous centre, will be at right angles with AC. But in the same time that C moves from C to B, the point A will have arrived at G in the rectilineal direction AG, which is equal and parallel to CB, and for the same reason, every point of the wave AC will be in GB, provided the transparent medium, whose surface is AB, transmitted the motion of the wave as quick as that of the other. But if we suppose that it transmits this motion slower; for example, one-third slower, then the point A will only have advanced *two-thirds* of CB, into the medium AB, and will therefore form a particular spherical wave, whose circumference SNR has A for its centre, and $AR = \frac{2}{3}$ AG or $\frac{2}{3}$ CB for its radius. By the same reasoning it may be shown, that the other points HH of the wave AC will, during the time that C has reached B, have not only arrived at the points K, K, in AB, but will have advanced into the medium by a space KN, KN, equal to $\frac{2}{3}$ of KM, KM, and will have created round the centres K, K, particular waves represented by circumferences, whose radii KN, KN, are respectively $\frac{2}{3}$ of KM, KM; that is $\frac{2}{3}$ of the continuation of HK, HK, to the straight line BG; for these radii would have been equal to the whole of KM, if the two transparent media had the same penetrability. But all these circumferences have for their common tangent the straight line BN, which is the tangent to the first circumference SNR at the point N, as is obvious from the parallelism of the lines AR, KR. The line BN, therefore, formed by the small arcs of these circumferences, terminates the motion which the wave AC has communicated to the transparent medium, and where this motion is found in much greater quantity than any where else. Hence this line is the propagation of the wave AC at the moment that C arrives in B; for there is no other line below the refracting plane AB, which, like BN, is the common tangent of all the particular waves. In order to understand how the wave AC has come successively into BN, we have only to draw the straight lines KO, KO, parallel to BN, and KL, KL, parallel to AC. In this manner it will be seen, that the wave CA has been bent from a straight line, as shown at LRO, LRO, and has again become a straight line at BN.

If we now draw EAF, cutting the plane AB at right angles at the point A, and AD perpendicular to the wave AC, DA will be the incident ray of light, and AN perpendicular to BN the refracted ray, since the rays are only straight lines, along which the parts of the waves are propagated.

If we now consider AB as the radius of a circle, BC will be the sine of BAC, and AN the sine of ABN. But BAC=DAE, or its supplement DAP, since each of them added to CAE make a right angle. And ABN=NAF, since BAN is the complement of both to a right angle. Hence the sine of the angle DAE is also to the sine of NAF, as BC to AN. But the ratio of BC to AN expresses the ratio of the velocities of light in the medium from which the wave AC came, and the medium by which it was refracted. Consequently the sine of the angle of incidence is to the sine of the angle of refraction as the velocities of light in the two media before and after refraction.

In order to observe how the luminous waves will be refracted in passing from a dense into a rare medium, let Fig. 4. be constructed in precisely the same manner as Fig. 3. with this difference only, that $\frac{3}{2}$ is substituted in place of $\frac{2}{3}$; and it will be found from the very same reasoning on this new figure, that when the point C of the wave AC has arrived at the point B of the refracting surface AB, every point of the wave AC will be advanced to BN; so that BC drawn perpendicular to AC will be to AN drawn perpendicular to BN as 2 to 3, and that this same ratio of 2 to 3 will be that of the sine of the angle of incidence EAD, and the sine of the angle of refraction FAN. Hence we see, that the refractions must be reciprocal, as experiment has determined; that is, the refracted ray, in passing from a rare into a dense medium, being supposed to be the incident ray when falling from the same dense medium upon the same rare medium, the former incident ray will now be the refracted ray.

The remarkable phenomenon of *total reflexion*, which happens in the kind of refraction we have been considering, is a necessary result of the Huygenian theory. For if the angle DAQ, or CBA, is such, that in the triangle ACB, CB is equal to two-thirds of AB, or greater; then AN cannot form the side of a triangle ANB, because it becomes equal to, or greater than AB, which ought to be perpendicular to it. Hence it follows, that the incident ray cannot in this case penetrate the refracting surface. If it should be asked why no light passes in this case through AB, since the arrival of the wave AC against the surface AB ought to produce a motion in the ethereal matter on the other side, the explanation given by Huygens is very satisfactory. Though an infinity of particular waves are generated in the ethereal matter below AB, Fig. 4. yet these waves cannot at the same instant have a common tangent either straight or curved; so that there is no line which terminates the propagation of the wave AC beyond the plane AB, nor where the motion is accumulated in a sufficient quantity to produce light. Hence when $CB \geqq \frac{2}{3}$ AB, the waves generated beyond the surface AB will have no common tangent, if from the centres K, K, we describe circles, having their radii equal to $\frac{3}{2}$ of LB, (the same as KM in the other case,) for all the circles will be inclosed in one another, and will all pass beyond the point B. As this case is a very interesting one in the theory, we have represented it in Fig. 5. where MN, PQ, are the circles described round K, K, with radii equal to $\frac{3}{2}$ of LB.

We shall now conclude this abstract of the Huygenian theory of refraction in homogeneous media, with the very curious proposition demonstrated by Huygens, but previously proposed by Fermat.

Prop. XXXII.

When a ray of light passes from a given point in one medium to a given point in another, it is refracted at the separating surface of the two media, in such a manner that it employs the least possible time in passing from the one medium to the other.

Let DE be the refracting surface, and let P be the point in one medium (of *Air*, for example,) from which the ray sets out, and the point C the other given point in the more dense medium, such as *Water*, and let the ray AB, incident at A, be refracted into the line BC, according to the usual law of the sines; or so that Sin. ABP : Sin. CBQ, as the velocity of light in air is to the velocity of light in water. Then the passage of the light along AB and BC is effected in the least time possible. Let us suppose that the light could pass quicker by the directions AF, FC, so that the point of refraction F is more distant than B from the point A, and draw FO parallel to AB, AO perpendicular to AB, BH perpendicular to FO, and FG perpendicular to BC. Then because HBF=PBA, and BFG=QBC, it follows that Sin HBF : Sin. BFG, as velocity of light in the medium A or air to the velocity of light in C or water; but these sines are the lines HF, BG; BF being radius. Hence HF and BG are to one another in the ratio of the above velocities; and if OF is the incident ray, the time in which the light passes along HF is equal to the time in which it passes along BG within the dense medium; but the time of describing AB is equal to the time of describing OH; consequently the time of describing OF is equal to the time of describing AB and BG. But the time of describing FC, the hypothenuse, must be longer than the time of describing GC; consequently the time of describing OFC will be longer than the time of describing ABC; and as AF is greater than OF, the time of describing AFC will exceed still more the time of describing ABC.

Let us next suppose, that the ray arrives at C by the route AK, KC, the point of refraction K being nearer to A than B is. Then draw KN parallel to BC, CN perpendicular to BC, and BM and KL respectively perpendicular to KN and BA. It may be shown, as before, that BL and KM, or the sines of the angles of incidence and refraction, are to one another as the velocities of the light before and after refraction. Now the time of describing LB is equal to the time of describing KM, and since the time of describing BC is equal to the time of describing MN, the time of describing LBC will be equal to the time of describing KMN. But the time of describing AK is longer than that of describing AL; consequently the time of describing AKN is longer than that of describing ABC. And as KC, the hypothenuse, is longer than KN, the time of describing AKC will be still more than the time of describing ABC. Hence it appears, that the time of describing ABC is the shortest possible.

Hitherto we have considered only the progress of the waves in a homogeneous medium. We shall therefore conclude this chapter with the explanation which Huygens has given of the refraction of light in media of variable density, such as the atmosphere of the earth.

If A, Fig. 7. is a luminous point, such as the top of a spire, the waves which are propagated from it in every direction, ought to extend themselves more widely above, as shown in the figure, and less widely below; and in other directions more or less, in proportion as these directions coincide more or less with the two extremes. Let BC be the wave which conveys to the eye of the spectator at B the impression of the light which emanates from A; and let BD be the straight line which cuts this wave perpendicularly. Then because the ray, or the straight line by which we judge of the place where an object appears to us, is nothing more than the perpendicular to the wave which arrives at our eye, it is obvious that the point A will be seen as if it were in the straight line BD, and higher than it is in reality. The light issuing from the point B has therefore moved through the atmosphere in a direction AEB, which is necessarily perpendicular to all the waves propagated from A as a centre.

For further information on the subject of this section, see Huygens's *Traité de la Lumiere*, chap. i. ii iii. and iv. Barrow's *Lectiones Opticæ*, Sect. ii. 4. Euler, *Conject. Phys.* Euler's *Letters to a German Princess*; and Young, in his *Syllabus*, Art. 382, &c. in *Phil. Trans.* 1800, p. 128; and in his *Elements of Natural Philosophy*, vol. ii. p. 613, &c.; and M. Fresnel's *Memoire sur la Diffraction de la Lumiere.*

CHAP. II.

On Catoptrics.

The word Catoptrics, from the Greek *κατα*, *from*, and *οπτομαι*, *to see*, is that branch of optics which treats of the *Reflexion of Light*, or of the changes of direction which light experiences when it is repelled or reflected *from* the surfaces of transparent or opaque bodies.

Prop. I.

When light is incident upon a plane or curved surface, the angle which the incident ray forms with a perpendicular to that surface at the point of incidence is equal to the angle which the reflected ray forms with the same perpendicular.

Let RS, MN, Fig. 8. be reflecting surfaces either plane or curved; AC a ray incident upon them at the point C, and CP a perpendicular to the surface at the point C. Then having drawn from C the line CB in the plane passing through ACP, so that PCB=PCA, CB will be the reflected ray. If we take any plane surface with a graduated semicircle, and make it coincident with the incident ray AC and the perpendicular CP, so that the point of incidence C coincides with the centre of the graduated semicircle, and if we admit a ray of light through a minute aperture at A, it will be found universally that whatever be the position of A, the arch AP, which measures the angle ACP, is equal to the arch PB, which measures the angle PCB, and that the reflected ray CB is in the same plane with AC and PC. Now the angle ACP is called the *Angle of Incidence*, and the angle PCB the *Angle of Reflexion*. Hence it follows, that in all reflexions, whether from plane or curved surfaces, *the angle of Incidence is equal to the angle of reflexion*, and that *the reflected ray is in the same plane with the incident ray*.

Cor. 1. If BC be made the incident ray, CA will be the reflected ray.

Cor. 2. If the ray PC be incident perpendicularly at C, it will be reflected back again in the direction CP, and if it is incident horizontally in the direction SC, it will be reflected horizontally in the direction CR, RCS forming one straight line.

Cor. 3. If we prolong AC to E, the angle BCE will measure the deviation of the reflected ray from its primitive path.

Cor. 4. When the ray is incident perpendicularly as at PC, its *angle of deviation* is 180°, or two right angles; when it is incident in the direction BC, so that BCP is 45°, the *angle of deviation* will be $2\times45^\circ=90^\circ$, or *one right angle*; and when it is incident at an angle of 90°, or SC, the *angle of deviation* will be nothing.

Def. A Mirror or Speculum is a piece of metal or glass, with a highly polished surface, which reflects the rays of light. It may be either *plane*, *concave*, or *convex*. When a glass mirror is used, the incident light is refracted at the first surface, and then reflected from a coat of tin and quicksilver, made to adhere to the posterior surface, for the purpose of increasing the brilliancy of the reflexion. When we speak of a mirror or speculum, therefore, we always mean a metallic one, where the light does not suffer any refraction before it is reflected.

Sect. I.—*On the Reflexion of Rays from Plane, Convex, and Concave Mirrors.*

Prop. II.

When rays of light are reflected from a plane mirror, the reflected rays have the same degree of inclination to one another as their corresponding incident rays.

Case 1. *Parallel Rays.*—Let AB, CD, Fig. 9. be two parallel rays incident upon the plane mirror MNOP; from their points of incidence B, D, draw the perpendiculars BE, DF; join BD, and let DH be the intersection of the planes CDF, GBD; or since BE, DF are both drawn perpendicular to the same plane, they are parallel, Geometry. Prop. V. Cor. 1.; and as AB, CD, are parallel, the angles of incidence ABE, CDF, are equal, Geometry, Prop. X. In consequence of the parallelism of EB, and FD, and AB and CD, the planes ABG, CDH, are parallel, Geometry, Prop. XI. and they are intersected by the plane GBDH; consequently DH is parallel to BG, Geometry, Prop. VII.; and EBG = FDH, Geometry, Prop. X. But EBG = angle of reflexion of AB, consequently FDH = angle of reflexion of CD; and as DH is in the plane CDF, CD is reflected in the direction DH, which is parallel to BG.

Case 2. *Diverging Rays.*—Let RAB, Fig. 10. be a pencil of diverging rays incident upon the plane mirror PB, and from R draw RF perpendicular to PAB, and cutting the surface of the mirror in P. Let AD be the reflexion of an incident ray RA, produce DA backward to F. Then, by Prop. I. p. 655. PAR = BAD = PAF, consequently in the right angled triangles PAR, PAF, the angles are all equal, and PA common; hence RP = PF, that is, the reflected ray AD proceeds as it came from a point F, on the other side of the mirror, and at the same distance from it as P. In like manner, it may be shown, that every other ray will proceed as if they diverged from F, and therefore F is the virtual focus of all the reflected rays. Since PRA=PFA, it may be shown in the same way that PRB=PFB; hence, taking equals from equals, the remainder AFB = ARB, that is, the rays after reflexion have the same degree of inclination as before reflexion.

Case. 3. *Converging Rays.*—If DA, CB, Fig. 10. is a pencil of incident rays converging to the point F, it follows from the above reasoning that they will converge to the focus R after reflexion. See Cor. 1. Prop. V. p. 657.

Prop. III.

If parallel rays are incident upon a convex or a concave mirror, they will be reflected to a focus equidistant from the surface and the centre of the mirror.

Let RA, RE, Fig. 11. be parallel rays incident upon the spherical mirror AEB, whose centre is C. The ray RE passing through the centre C, and therefore falling perpendicularly on the mirror at E, will be reflected in the direction EC. Having joined CA, and made the angle CAq=CAR, the ray RA will be reflected in the direction Af. At the point of incidence A, draw the tangent GH, cutting CE produced in H. Then, on account of the parallelism of RA, RE, the angle RAC = ACE = CAf, consequently Cf=fA. But fAH = RAG = AHf, Geometry, Prop. XXI. consequently Af = fH, and CF=FH. If we now suppose the ray RA to approach the axis RE, the arch AE will diminish, and its secant CH will ultimately become equal to the radius CE, consequently fH will then become equal to fE, and therefore Cf=fE.

When the ray R′ A, falls upon the convex surface of AEB, it may be shown by the very same reasoning, that f, which is now the virtual focus of the reflected rays, or their focus when produced backwards, is equidistant from C and E.

Cor. If several pencils of parallel rays be incident nearly perpendicularly upon a spherical mirror, the foci of the reflected rays will be in a spherical surface concentric with that of the mirror. For since each focus is by the proposition equidistant from the centre of the mirror, the distance of all the foci from the mirror must be exactly the same; that is, they must be in a surface concentric with that of the mirror.

Prop. IV.

When diverging or converging rays are incident upon a concave or a convex mirror, the distance of the principal focus, from the centre is a mean proportional between the distance of the radiant point from the principal focus, and the distance of the principal focus from the conjugate focus.

Let AEB, Fig. 12. be the spherical mirror, whose centre is C; and RA, RE, two rays diverging from R, and incident upon the mirror AB. The ray RE, which passes through the centre, will be reflected back again in the direction ER. Having joined CA, draw Ar for the reflected ray, making the same angle as the incident ray with CA. Draw DA parallel to RE, make $CAe = CAD$, and bisect EC in F. Then, since $DAC = CAe$, and $RAC = CAr$, we have $DAR = eAr$. But in the triangles ARe, Are, the angle reA is common, and consequently they are similar. Hence $Re : eA = eA : er$; or, by Prop. iii. as $eA = eC$, we have $Re : eC = eC : er$. If we now suppose the point A to approach C, then the point e will ultimately coincide with F, and therefore we have ultimately $RF : FC = FC : Fr$.

By constructing the figure for converging rays, the same result will be obtained by the very same reasoning, and if the lines in Fig. 12. are all produced behind the mirror AB, we shall have similar results for rays incident upon a convex mirror.

Cor. 1. When the radiant point is in the centre of the mirror, the rays being all incident perpendicularly, will be reflected back in the same line, and therefore the radiant point and the focus will coincide in the centre.

Cor. 2. As the radiant point R approaches to the mirror, the focus r recedes from it. When R arrives at C, r arrives also at C, as in Cor. 1. and when R gets to the right hand of C, r gets to the left, and gradually recedes to the left as R advances to F. When R reaches F, the point r has receded to an infinite distance, and the reflected rays are parallel; but when R passes F, r becomes a virtual focus on the right hand of the mirror AB, or the point from which the diverging reflected rays now appear to issue. As R approaches to E, r approaches to E, and the two conjugate foci finally coincide at the vertex E of the mirror.

Cor. 3. As $Re : eC = eC : er$, we have $Re : RC = eC : r$, and $Re : eC = RC : Cr$: when A has approached to F, we shall have ultimately $RF : EC = Re : Cr$.

Cor 4. As $CAR = CAr$, we have, (by Geometry, Prop. XVII.) $RA : Ar = RC : Cr$, and ultimately, $RE : Er = RC : Cr$.

Cor. 5. As the conjugate foci of rays meet at r only when they are incident nearly perpendicularly upon a mirror, a spherical mirror is incapable of reflecting incident rays to the same focus, unless in the case of Cor. 1. when they radiate from and return to the centre. There is, therefore, a *spherical aberration* in all mirrors, analogous to that which exists in lenses of a spherical form.

Sect. II.—*On the Formation of Images by Plane, Convex, and Concave Mirrors.*

Prop. V.

When any object is placed before a plane mirror, the image of it appears at the same distance behind it, of the same magnitude, and equally inclined to the mirror.

Let MN, Fig. 13. be a plane mirror, and AB an object placed before it, and let the position of the object be such that the reflected rays may enter an eye placed at H. From A and B let fall upon the mirror the perpendiculars Aa, Bb. Then by Prop. II. Case 1. rays AF, AG diverging from A, will be reflected in the lines FH, GK, as if they came from the point a, so situated that $EA = Ea$; and hence the point A, which is rendered visible to the eye at H by the rays FH, GK, will be seen at the point a. In like manner it may be shown, that the point B of the object, which is rendered visible to the eye at H by the rays fH, gK will appear at b, so situated that $GB = Gb$. By taking any other rays at pleasure, divergent from any other point of the object AB, it may in a similar manner be shown, that they will have their foci in points of the line ab, formed by drawing perpendiculars from the given points of the object. Hence, since Aa is parallel to Bb, and $EA = Ea$, and $GB = Gb$, the image ab of the object AB will be of the same magnitude as the object, and will be equally inclined to the mirror.

Prop. VI.

If the image of an object is seen by reflexion from two plane mirrors, and if the reflexion is made in a plane perpendicular to their common intersection, the angular deviation of the image from the object will be equal to twice the inclination of the reflecting mirrors.

Let AB, CD, Fig. 14. be the two plane mirrors, whose inclination is BGD, and let a pencil of rays PA, PB, diverge from any point P, and after reflexion at the points A, B be again reflected to the eye at H, from the points C, D, of the second mirror. Continue PB meeting the same ray DH in H, and continue HD and KC to O. The image will appear at O, and its angular deviation, or distance from the object, will be PHO, which will be equal to twice BGD. As the angle $HBG = ABP = DBG$, the sum of any two of these equals will be equal to double of either of them, or $DBH = 2\,DBG$. For the same reason $BDO = 2\,BDC$. But Euclid xxxii. 1. $BGD = BDC - DBG$; and multiplying by 2 we have $2\,BGD = 2\,BDC - 2\,BDG$; consequently by substitution $2\,BDG = BDO - DBH = BHD$.

Scholium.

This proposition constitutes the principle upon which Hadley's quadrant is constructed. See Quadrant.

Prop. VII.

If an object is placed between two plane mirrors, inclined to each other at any angle, several images of any object placed between them will be formed, and these images will be arranged in the circumference of a circle, whose centre is the intersection of the two planes, and whose radius is the distance of the object from that centre.

Let AO, BO, Fig. 15. be two plane mirrors, whose inclination is AOB, and let C be an object placed between them. Upon O as a centre, and with OC as radius, describe the circle ENQGE, and from C draw CE perpendicular to AO in D, and meeting the circle in E; EG perpendicular to BO at F; GH perpendicular to AO; and HV perpendicular to OB. In like manner, from C draw CL perpendicular to OB in K, LN perpendicular to OA in M, NP perpendicular to OB, and PQ perpendicular to OA. Now, as the points C, E, are in the circle whose centre is O, and CE perpendicular to OA, we shall have the triangles ODE, ODC, equal, and CD = DE; and, in like manner, it may be shown, that all the other lines EG, CL, LN, &c. &c. are bisected in points F, K, and M, lying either in the surface of the mirror OA, OB, or in these lines produced. Hence, it follows, that E is the image of the object C, formed by the mirror OA; G the image of the object E, formed by the mirror OB; L the image of E, formed by OB; N the image of L, formed by OB, every image being an object from which a new image is formed by the other mirror. The different images, therefore, formed by successive reflexions between the mirrors, are arranged in the circumference of a circle described round O as a centre, and passing through the object C.

Cor. 1. If we consider the whole angular opening of the mirrors, viz. the sector OAB as the object, images of it will be formed in a circle whose centre is C, and the images of any point C, viz. those at E, G, L, M, will occupy the same position in each image of the sector, that C does in the real sector ABO.

Cor. 2. If the inclination of the mirrors gradually diminishes, the inclination of the lines CE, EG, will also diminish, and the number of images increase, and when the inclinations are infinitely small, so that the mirrors become parallel, the lines CE, EG, will coincide, and the images will all be arranged in a straight line, passing through the object, and perpendicular to both mirrors, and will be infinite in number. But as a portion of light is lost at every reflexion, they will gradually diminish in brightness, and will soon become invisible.

Scholium.

This proposition forms the foundation of the Kaleidoscope, in so far as the *multiplication* of the images is concerned; but it has no relation whatever to the *principle of symmetry* in the combination of the images, which is essential to the production of beautiful forms by multiplied reflexions. The proposition above demonstrated is true, independent of the position either of the object or the eye, provided that the rays from the former fall upon the mirror, and the latter receives the reflected rays; but in order that the images may be *actually seen* arranged in the circumference of a circle, the object and the eye must have certain positions. See the article Kaleidoscope in this work, vol. xii. and Dr. Brewster's *Treatise on the Kaleidoscope*. Edinburgh, 1819.

Prop. VIII.

The number of images of any object placed between two inclined plane mirrors, whose inclination is an aliquot part of four right angles, is equal to the number of times that the angle, formed by the mirrors, is contained in four right angles.

Let AO, BO, Fig. 15. be the mirrors, as in the last proposition; then, since CE, LN, GH, &c. were drawn perpendicular to the same mirror OA, they will be parallel; and, for the same reason, CL, EG, NP, &c. will be parallel. Consequently, Geom. Prop. X. the arches of CE, LG, NH, PV, will be equal. Call the inclination of the mirrors, or AOB $= i$, the arches CA $= a$, and CB $= b$; then we have CE $= 2a$, and CL $= 2b$, CN $= 2a + 2b = 2i$, CH $= 2i + 2a$, and CNQ $= 2i + 2a + 2b = 4i$. Hence the distances of the images E, H, Q, from C are,

Distance of C from E $= 2a$
Distance of C from K $= 2i + 2a$
Distance of the next $= 4i + 2a$

$$2ni - 2i + 2a = 2ni - 2a,$$

where n is the number of images. Now this series will be continued while $2ni - 2b$ is less than CNR or $180° + a$, and therefore the number of images n in this series, is the whole number immediately below $\frac{180 + a + 2b}{2i} = \frac{180 + i + b}{2i}$. But there is a second series of images formed at N, Q, whose distances are $2i, 4i, 6i, \ldots\ldots 2mi$, a series which will be continued while $2mi$ is less than $180 + a$; consequently, the number of images is the whole number immediately below $\frac{180 + n}{2i}$. In the same way, it may, be shown, that the number of images formed by reflexion from the mirror BO will be the whole number immediately below $\frac{180 + i + a}{2i}$ and $\frac{180 + a}{2i}$. But, if i is contained an even number of times in 180°, the number of images in each of the *four* series will be $\frac{180°}{2i}$, because $\frac{180° + i + b}{2i} = \frac{180°}{2i} + \frac{i + b}{2i}$; the latter part is neglected, being less than unity. Hence the number of images in all the four series will be $4 \times \frac{180}{2i} = \frac{360}{i}$. If, on the other hand, i is contained an odd number of times in 180°, $2i$ will be a measure of $180° + i$ or $180 - i$, and the number of images will be $\frac{180 + i}{2i} + \frac{180 - i}{2i} + \frac{180 + i}{2i} + \frac{180 - i}{2i} = \frac{360}{i}$. See Wood's *Optics*, (whose demonstration of this proposition we have adopted,) Prop. xiv. p. 38, and the *Treatise on the Kaleidoscope*, p. 10—15.

Prop. IX.

When any object is placed before a convex mirror, the image of it appears nearer to the surface of the mirror, and of a less size.

Let MN, Fig. 16. be the convex mirror, whose centre is C, and AB the object, and let the position of the object be such, that the reflected rays may enter an eye placed at H. From C draw CA, CB, cutting the mirror MN in E and F. The rays AF, AG, will be reflected to H and K, making equal angles with the perpendiculars passing from C through F and G, and will therefore enter the eye as if they came from some point a, at the intersection of these rays with the perpendicular AC; consequently the point A of the object will have its image visible at a. In like manner, rays Bf, Bg, falling upon the points f, g. will be reflected to the eye as if they came from b, the point where they intersect the perpendicular drawn from B to C. Now, as the reflected rays diverge more than the incident ones, the point a will be nearer the mirror than A, and the image *a b* will be less than the object AB in the ratio of C *b* to CB.

Prop. X.

When an object is placed before a concave mirror, the image of it has various magnitudes and positions depending on the distance of the object from the mirror.

1. When the object is between the concave mirror and its principal focus, the image appears behind the mirror, and is more distant from it, and of greater magnitude than the object.

Let MN, Fig. 17. be the concave mirror, F its principal focus, C its centre, and AB the image. From C draw CA *a*, CB *b*, passing through A and B, and let the image be so placed that the reflected rays will reach the eye at H. The rays AD,AG, proceeding from A, and B *d*, B *g*, proceeding from B, will be reflected to the eye at H, making equal angles with the perpendiculars CG, C *g*, &c. and they will diverge less than before reflexion, as if they had come from a remote point *a*, situated in the intersection of those rays with the perpendicular CA *a*. In like manner the rays B *d*, B *g*, will enter the eye at H, as if they had proceeded from *b*, a point where they intersect CB *b*. These points *a*, *b*, will be farther from MN than A and B are, and the image *a b* will be greater than AB, in the ratio of C *b* to CB.

2. When the object is withdrawn, so as to be placed in the principal focus F, the rays will, by Cor. 3. of Prop. IV. be reflected in parallel directions, so that the image will be formed at an infinite distance.

3. When the object is situated between the principal focus and the centre, the image is formed on the other side of the centre, and is inverted and larger than the object.

Let MN, Fig. 18, be the mirror, C its centre, F its focus, and AB the object. Through C draw the lines CA, CB, and continue them backwards to *a* and *b*. Then let AD, AG; B *d*, B *g*, be two pencils of rays flowing from the extremities A, B. These rays will, after reflexion in the directions D *a*, G *a*, and *d b*, *g b*, meet the perpendicular lines C *a*, C *b*, in the points *a*, *b*, at a greater distance from the mirror than the centre C, and will then form an image of those points of the object. The image is therefore more remote from C than the object is, and the size of the one will be to that of the other as *a* C is to AC; that is, the image will be larger than the object.

4. When the object is situated beyond the centre, the image will then be formed between the centre and the principal focus, and will be inverted and less than the object.

This is the converse of the preceding, and will be made obvious by considering the rays as first flowing from *a b* and converged to AB.

5. When the middle part of the object is placed in the centre of the mirror, the object will coincide with the image, and the image will be inverted.

That the centre of the image and that of the object will be coincident, is obvious from Cor. 1. of Prop. IV. p. 646. If A, B, Fig. 19. are the extremities of the object, then a ray AD falling on the mirror of MN at D, will be reflected to B, because the angle ADC=BDC; and in like manner a ray BD falling from B will be reflected to A, consequently the image, though coincident with the object, will be inverted.

Cor. 1. In every case where the rays are converged so as to form a positive image in front of the mirror, an observer will perceive this image suspended in the air, and perfectly distinct, provided his eye is above seven inches distant from it, in the very same manner as he would see any other object. This will be very obvious, from considering that all the rays which form the image cross one another at every point of the image, and therefore diverge from every point of it in every direction in front of it, as if it were a real object. The object will therefore be seen by those rays, provided it is at or beyond the least distance of distinct vision.

Cor. 2. When the eye is situated between the image and the mirror, and directed to the mirror, the object will be seen behind the mirror, and will appear more indistinct and larger the farther the eye recedes from the surface to the place of the image.

Let AB, Fig. 20, be the object, and *a b* its image formed by the mirror MN, between the centre C and the mirror. Let *o p* be the pupil of the eye, which will receive the rays H *o*, K *p* on their way to the point *a* of the image. The point A of the object, therefore, from which these rays come, will be seen diffused over the space RS, and for the same reason the rays K *o*, L *p*, from the point B will be received by the eye, and the point B will be diffused over TV, so that the object will seem to fill the space RV, but it will be very indistinct, as all the intermediate points of AB will have their diffused images between R and V. If the pupil is now withdrawn from the mirror to *e f*, it will then receive the reflected rays E *e*, G *f*, and also L *e* and O *f*, and by means of the two first the image of the point A will be diffused over YX, and by means of the two last the image of the point B will be diffused over VZ, and consequently the object will appear to occupy the more enlarged space XZ.

Prop. XI.

To determine, in general, the magnitude and situation of images formed by concave or convex mirrors.

In Figs. 21, 22, 23. let MN be the mirror, C its centre, and AB the object, the magnitude and situation of the image of which is required. Through its extremities A, B, and the centre C of the mirror, draw the lines AC, BC, and produce them in Figs. 22 and 23; and as these lines are perpendicular to the surface of the mirror, the extreme points of the image corresponding to A and B must be somewhere in them. Through the middle point F of the object and the centre C, produced in Figs. 22 and 23. till it meets the mirror in G, and this line will likewise be at right angles to the mirror. Through G draw GA and GB, till they intersect the lines CA, CB; and the points *a*, *b*, where this intersection takes place, will be the points where the image of the extreme points A, B, are formed. The ray AG, proceeding from A, will be reflected to B, because FA =FB by construction, and AGF=BGF, and FG a perpendicular at the point B. Hence the image of the point A must be in the line BG as well as in the line AC, and consequently it must be at their intersection in the point *a*. For the same reason the image of the point B will be formed at *b*.

When no intersection of the rays AG, AC takes place, then the object AB is in the focus of parallel rays, and the rays issuing from A will be reflected in parallel directions, and will form no image whatever.

Cor. 1. The image of any object subtends at the vertex of the mirror, and also at the centre of the mirror the same angle. This is manifest from Figs. 21 and 23, where $a\,Gb = AGB$, and $a\,C\,b = ACB$.

Cor. 2. The magnitude of the image is to the magnitude of the object, as the distance of the image from the vertex of the mirror is to the distance of the object from the same vertex; and also as the distance of the image from the centre of the mirror is to the distance of the object from the centre. In Figs. 21, 22, and 23. $a\,b : AB = Gf : GF$, and $a\,b : AB = cf : CF$.

Prop. XII.

The image of a rectilineal object formed by a spherical mirror is a conic section.

Let AEB, Fig. 1. be the mirror, whose centre is C, RR′ the object placed before it, and having drawn through C the line DCN, at right angles to RR′, draw CR, CR′ through any point R′ R′ of the object, and continue these if necessary. The image of the points R′s R′ will obviously be in some points; suppose $r\,r'$ of the lines CR r, CR′ r'. Bisect CE in F, and having taken $CD = CP$, bisect CE in F, and from r and r' draw r H, r H′ parallel to DN, and $r\,r'$ parallel to RR′.

Now, since r is the image of the point R $RF : FC = CR : C\,r$, and Geom. Prop. III. $RF : CR = FC : C\,r$. But $CR : C\,r = CP$, or $CD : CS$, consequently $RF : FC = CD : CS$, and by Geom. Prop. IV. and V. $RF : RF \pm FC = CD : CD \pm CS$, that is, $RF : CR = CD : DS$, or H r; therefore $CD : H\,r = FC : C\,r$, and Geom. Prop III. $CD : FC = H\,r : C\,r$, that is, H r has an invariable ratio to C r, and consequently r is a point in the conic section whose focus is in C, and whose directrix is DH. In like manner it may be shown, that the point r', and all other points of the image, is in a conic section.

The conic section is a *Parabola* when $CP = CF$, in which case $H\,r = C\,r$; and it is an *Ellipse*, or *Hyperbola*, according as CP is greater or less than CF.

Scholium.

The reader will find this curious subject treated at much greater length in Barrow's *Lectiones Opticæ*, Lect. xvii. and xviii. Smith's *Optics*, vol. ii. Remarks, p. 72. where the various cases are illustrated in separate diagrams; and Wood's *Optics*, p. 43.

Sect. III.—*On the Reflexion of rays to a single Point by Parabolic and Elliptical Mirrors.*

It appears from some of the propositions in Sect. I. that those rays which are incident nearly perpendicularly on spherical mirrors, are reflected to a point farther from the vertex of the mirror than those rays which fall more obliquely. This deviation of the rays from a mathematical focus is called the *Spherical Aberration* of the mirror.

As the accurate convergency of the incident rays is more necessary to the perfection of instruments consisting of mirrors, than in those consisting of lenses, it is of great importance to know what is the particular form of the mirror which will produce this desirable effect.

Prop. XIII.

If the reflecting surface of a mirror is a portion of a Paraboloid formed by the revolution of a parabola round its axis, parallel rays will converge accurately to its focus if it is concave, and will diverge accurately from its focus if it is convex.

Let AEB, Fig. 2. be a parabola, which forms a paraboloidal surface by its revolution round its axis RFE, and let RA, RE, RB, be parallel rays incident upon it at the points A, E, B. Let F be the focus of the parabola. Join AF, BF, and draw GH, touching the parabola in A. Then by Conic Sections, Prop. VI. the angle $GAR = HAF$; but GAR is the complement of the angle of incidence, and therefore HAF is the complement of the angle of reflexion; consequently AF will be the reflected ray. In the same way it may be shown, that every other ray, whether near the axis RE or remote from it, will be reflected to the focus F.

By producing RA to R′, and FA to r, and considering R′A as a ray falling on the *convex* surface AEB, it may be shown by the same reasoning, that $R'AH = r\,AG$, and that r F is the reflected ray, and diverges accurately from F.

Cor. If the rays *diverge* from the focus F, either *really*, as when the mirror is *concave*, or *converge virtually* to it, as they do when the mirror is *convex*, they will be reflected parallel to the axis RE in the direction AR or AR′.

Prop. XIV.

If the reflecting surface of a mirror is a portion of a Spheriod, or an Ellipsoid, formed by the revolution of an ellipse about its greater axis, rays diverging from one of its foci will be reflected accurately to the other focus if it is concave; or rays converging to one focus will diverge accurately from the other focus if it is convex.

Let AEB, Fig. 3. be a portion of an ellipse, by whose revolution round its axis an ellipsoidal surface is formed. Let R and F be its foci; RA, RE, RB, rays diverging from R, and incident upon the points A, E, and B: and GH a tangent to the ellipse in the point A. Join AF, BF. Then since by Conic Sections, Prop. VIII. the angle $HAF = GAR$, and since GAR is the complement of the angle of incidence, HAF is the complement of the angle of Reflexion; consequently AF will be the reflected ray. In like manner it may be shown, that every other ray, whether near the axis RE or remote from it, will be reflected to the same point F.

By producing RA to R′, and FA to r, and considering R′A as a ray falling on the convex surface, it may be shown in a similar manner, that $R'AH = r\,AG$, and that r F is the reflected ray, and diverges accurately from F.

Cor. If the rays *diverge* from the focus F, either *really*, as they do when the mirror is *concave*; or *con-*

verge virtually to it, as they do when the mirror is *convex*, they will be reflected to the other focus either in the direction AR or AR′.

Prop. XV.

If the reflecting surface of a mirror is a portion of a Hyperboloid, generated by the revolution of a hyperbola about its axis, rays converging to one focus will be reflected to the other focus if it is concave, or rays diverging from one focus will diverge virtually from the other focus if it is convex.

Let AEB, Fig. 4. be a hyperbola, by the revolution of which round its axis RE a hyperboloidal surface is generated. Let R and F be its foci; R′A. R′E, R′B, rays converging to one of its foci R, and incident upon the points A, E. B. Join AF, BF, and draw GH, touching the hyperbola in A. Then by Conic Sections, Prop. VIII. the angle R′AG = HAF, and since R′AG is the angle of incidence, HAF must be the angle of reflexion, and AF the reflected ray. In the same manner it may be shown, that every other ray converging to R will be reflected to the other focus F. For the same reason, rays diverging from the one focus R, and falling on the convex surface AEB, will be reflected in directions A *r*, B *r*′, diverging virtually from F.

Cor. If the rays *diverge* from the focus F, either *really*, as they do when the mirror is *concave*; or *converge* to it *virtually*, as they do when the mirror is *convex*, they will be reflected so as to diverge virtually from R, or virtually from F.

Sect. IV.—*On the Spherical Aberration of Mirrors, and Caustic Curves formed by Reflexion.*

As rays can be converged accurately to positive foci only by paraboloidal, ellipsoidal, and hyperboloidal mirrors, and as it is extremely difficult to communicate these figures to the surfaces of polished metals, it becomes of importance to determine the amount of the aberration when they have a spherical form.

Prop. XVI.

When parallel rays are reflected from a spherical mirror, whose aperture is not large, the longitudinal aberration of the extreme ray is nearly equal to half the versed sine of the semi-aperture.

Let ACB, Fig. 5. be a spherical reflector, whose centre is E, its vertex C, its semi-aperture AC, the sine of its semi-aperture AP, and the versed sine of its semi-aperture PC. Let the extreme marginal ray NA be reflected in the direction AG, intersecting the axis CE in *f*, which will therefore be the focus of extreme parallel rays. Join EA, and upon E as a centre, with the radius EA, describe the arch AD, and join AD.

Since by Prop. XXVII. PD : PC = CE : D*f*, and as CE is nearly equal to twice DF, PD will be nearly equal to 2PC. But $2fF = 2fE - 2EF = ED - EC = CD$, or nearly equal CP. Consequently $fF = \frac{1}{2}$ CP nearly, or nearly *one-half* of the versed sine of the semi-aperture.

The truth of this proposition might have been deduced still more easily from Prop. XXVII. *p*. 643. In Fig. 6. of Plate CCCCXXX. let us suppose EM the sine of the angle of refraction diminished to nothing, and then to become negative and equal to EN, the sine of the angle of incidence, and the refraction of the ray to be changed to reflexion, as in Fig. 5. Plate CCCCXXXII. then by Prop. XXVII. we shall have

$fF : CP = m^2 : (-m-n)\,n = n^2 : 2\,n^2 = 1 : -2.$

Cor. 1. The longitudinal aberration is *exactly* equal to the difference between the secant and the radius of the semi-aperture; for $2fF = CD$, and CD is the difference of these quantities.

Cor. 2. The *longitudinal aberration* $fF = \frac{AP^2}{4CE}$; for $CP = \frac{AP^2}{2CE}$, Euclid, VI. 13, and dividing this by 2, as $fF = \frac{1}{2}$ CP, we have $fF = \frac{AP^2}{2CE} \times \frac{1}{2} = \frac{AP^2}{4CE}$.

Cor. 3. The *lateral aberration* $FG = \frac{AP^3}{2CE^2}$. In the similar triangles fFG, fAP, $FG : Ff = AP : Pf$ nearly. Consequently $FG = \frac{Ff \times AP}{Pf}$; but $Pf = \frac{1}{2}$ CE nearly, and $Ff = \frac{AP^2}{4CE}$, and substituting these values in the preceding value of FG, we have $FG = \frac{AP}{\frac{1}{2}CE} \times \frac{AP^2}{4CE} = \frac{AP^3}{2CE^2}$.

Cor. 4. The focal distance of the mirror being given, the longitudinal aberrations will vary as the squares of the diameters of the apertures, and the lateral aberrations as the cubes of the diameters of the apertures. This follows from the two preceding corollaries, AP being half the diameter of the aperture.

Prop. XVII.

When diverging or converging homogeneous rays are incident on a spherical mirror, to determine the spherical aberration.

Let DO, Fig. 6. be the reflecting mirror, R the radiant point from which the ray RD diverges, DK the reflected ray, F the principal focus. Now as it is the same thing, whether the refracted ray goes backward or forward in the line DK, we may suppose the angle of refraction SDK, and its sine, in Fig. 8. of Plate CCCCXXX. (see Prop. XXIX. p. 645.) diminished to nothing, and then made negative, and equal to the angle of incidence SDR. The method of calculation will then remain the same as in Prop. XXIX. and we have only to substitute in place of n in the formula of that proposition $-m$, or the sine of the angle of reflection, after it has been made negative and equal to the angle of incidence. Hence the expression of the aberration for refracted rays, or

$$KF = \left(\frac{RO - SO}{RO + \frac{n}{m-n}SO}\right)^2 \times \frac{n^2\,RO - n^2\,SO - m\,n\,SO}{\overline{m-n} \times m\,RO} \times XO,$$

will become, for reflected rays,

$$FK = \left(\frac{RO - SO}{RO - \frac{1}{2}SO}\right)^2 \times \frac{1}{4} XO.$$

Cor. 1. In order to obtain an expression of the aberration in terms of the semi-aperture in place of the thickness of the lens, we have (see Cor. 1. of Prop, XXIX. p. 545.) $XO = \frac{XD}{2OS}$, which, substituted in place of XO in the above formula, gives $FK = \left(\frac{RO - SO}{RO - \frac{1}{2}SO}\right) \times \frac{1}{4}\frac{XD}{SO}$.

Cor. 2. When SO becomes infinite, and the reflecting surface a plane one, the aberration becomes nothing.

Cor. 3. Since Rf, Sf, Kf are continued proportionals, they are proportional to their sums or their differences; and since we have by the proposition $FK : \frac{1}{2} XO = RS^2 : Rf^2$, then $FK : \frac{1}{2} XO = SK^2 : SF^2$. Consequently when the point of incidence D is given, XO and SF are invariable. The aberration, or FK, will vary with SK^2, or the square of the distance of the focus from the centre of the surface.

Prop. XVIII.

To explain the formation and general properties of caustics formed by reflexion.

Let ACB. Fig. 7. be a concave mirror, whose centre is E, and principal focus F, and let a pencil of rays, AR, diverging from R, fall upon its upper half AC, at the points 1, 2, 3, 4, 5, the ray R1, near the axis, will have its conjugate focus near the conjugate focus *f*, for central rays, but a little to the right hand of it. The next ray, R 2, will cut the axis nearer F, and so on with all the rest of the rays, as may be easily ascertained, either by calculating the aberration, and setting the aberration for each ray, from *f* towards C, or what is easier, by drawing a line fom E to each point of incidence, and drawing the reflected ray so that it and the incident ray may make equal angles with the perpendicular from E. When this is done, the rays will intersect one another, as in Fig. 7. and form by their intersections the caustic curve stretching from A to *f*. Had the light fallen also upon the lower half of the mirror, a similar caustic, shown by a dotted line, would also have been formed from *f* to B. When the point of incidence, therefore, beginning at A, moves along the concave surface of the mirror from A to C, the conjugate focus of two contiguous rays, or of an infinitely slender pencil, will describe the caustic from A to *f*.

Let the radiant point R be supposed to be as far from C to the right hand, as it is now to the left, the divergent rays will fall upon the convex surface of the mirror, and will diverge after reflexion, as if they came from the various intersections in the caustic A *f*. Hence it follows, that an imaginary caustic will be formed behind the convex surface, and this imaginary caustic will be exactly the same as the real one, shown in Fig. 7. as formed by a concave surface.

If we suppose the concave mirror ACB, in Fig. 7. to be nearly completed as at ASB, then the divergent pencil A *f* S, incident on the convex surface AS, will form an imaginary caustic A ϕ, less than A *f*, and joining it at the points A, B.

As the radiant point R recedes from the mirror, the tangent *c f* of the real caustic will diminish on account of the conjugate focus *f* approaching to F, and for the same reason the tangent S φ to the imaginary caustic will increase, and when R is infinitely distant, the cusps of both caustics will coincide with F′ and F, and will be of the same size and shape.

If, on the contrary, the radiant point approaches to the mirror, the point *f* of the real caustic will approach to E, and the tangent CF will lengthen; but the point φ of the imaginary caustic will approach to S, the tangent S φ will shorten, and when R coincides with S, φ will also coincide with S; the imaginary caustic will vanish, and the real one will have its two opposite summits meeting in the point S.

If the radiant point R, Fig. 8. now enters the circle of the reflecting mirror, and is nearer to E than S, the intersection of the rays will form the very remarkable caustic shown in Fig. 8. where the two long curved branches meet in a focus at *f*. When R is nearer to S than E, the curved branches that meet in *f* will diverge, and have an imaginary focus on the other side. When R is equidistant from S and E, these curved branches are parallel lines, and when R coincides with E, the whole caustic is condensed into a single point in the centre E.

When the radiating point R, Fig. 9. has approached the principal focus F, and is a little way within it, as in Fig. 9. so that the rays R 1, R 1, are reflected parallel to the axis RC, the rays R 2, R 2, will meet at *f* 2, and the rays R 3, R 3, at *f* 3, and if we oppose rays incident nearer C than R 1, and R 1, they will be reflected so as to diverge, and have a virtual focus behind the mirror; so that, by exposing only the part of the mirror between 1 and 1, it will diverge rays incident from R; by exposing only the part between 2 and 1, and 2 and 1, it will render parallel rays incident from the same point R; and by exposing only the parts without 2 and 2, it will converge to foci, *f* 2, *f* 3, rays incident from the same point R.

Scholium.

Caustic curves may be seen in a very perfect manner in the bottom of cylindrical China vessels, exposed to the light of the sun or of a candle; or, when these are too deep, an artificial bottom for receiving the caustic may be formed by inserting a circular piece of card parallel to the bottom of the vessel, or by pouring in milk, or any fluids having a white opacity. By far the best way, however, of exhibiting all the varieties of caustics, is to take a piece of steel spring, highly polished, so that by bending it into curves of various sizes and shapes, and placing its edge perpendicular to a piece of white paper or ground glass, the caustics will be finely exhibited. Even by the aid of a piece of blue watch spring, the caustics may be well represented.

Sect. V. *On the Theory of the Reflexion of Light.*

The reflexion of light from the surfaces of bodies, is a phenomenon of more difficult explanation than that of its refraction. Before the time of Sir Isaac Newton, it was generally believed that light was reflected by impinging upon the solid parts of the reflecting surface.

in the same manner as a ball of ivory is reflected from a solid plane. Sir Isaac Newton, however, has shown the improbability of this opinion, and that, if it were true, the reflexion of polished bodies could not be so regular as it actually is. He shows, that, however fine be the powder with which glass is polished, the polish is effected by grating and scratching it, and removing its protuberances; and that when it is polished, its roughness is only brought to a very fine grain, so that the scratchings and gratings of the surface become too small to be visible. Hence, if the roughness of the surface, or rather the little pits and protuberances upon it, bear any sensible proportion to the magnitude of the particles of the incident light, it is manifest that if this light actually impinged against these pits and protuberances, it would be scattered as much by the most polished as by the roughest glass. As the light, however, is more perfectly and abundantly reflected from polished surfaces, Sir Isaac Newton concluded that this regular reflexion of light was not owing to single parts of the body acting upon single particles, but to *some power of the body evenly diffused all over its surface, and by which it acts upon the rays without immediate contact.*

When a pencil of light is incident perpendicularly upon *Water*, only 18 rays out of 1000 are reflected, while the greater part of the remaining 982 are transmitted. When the same pencil is incident at an angle of 40°, 22 rays are reflected; at an angle of 65°, 97 rays are reflected; at an angle of 75°. 211 rays; at an angle of 80°, 333 rays; at an angle of 85°. 501 rays; at an angle of 87½°, 614 rays; at an angle of 89°, 692 rays; and at an angle of 89½°, 721 rays are reflected. If in place of water we substitute *Glass*, we shall find that 25 rays are reflected at a perpendicular incidence; and that the glass always reflects more light than the water till at very great angles of incidence, such as 87½°, when it reflects only 584 rays, while water reflects 614.* In like manner, bodies reflect more the higher that their refractive power is, although at very great angles of incidence they reflect less light than water. From this, and other facts, Sir Isaac Newton concluded that bodies *reflect and refract light by one and the same power, variously exercised in various circumstances.*

Thus, in Fig. 10. he supposes that if AB is the surface of a transparent body, whose space of refracting activity extends to *o p* and *m n*, its space of reflecting activity will extend to *s t* beyond *o p*; or that while a ray of light R *r* is passing through the space of reflecting activity between *s t* and *o p*, it is influenced by a repulsive force acting in lines perpendicular to the surface AB of the body. When a pencil R *p*. R′ *p*′, therefore, is incident upon the body AB, a portion of it R *p* passes through the space of reflecting activity, and is refracted in the direction R′ *p*′ *q*′ *r*′ *s*′, in the manner formerly explained in p. 651; but another portion R *p*, experiencing the action of the reflecting force, is bent upwards in a curve line *p q*, from the united influence of the vertical repulsive force, and the oblique force with which it moves; and when it reaches the boundary *o p* of the space of refracting activity, where the reflecting or repulsive force is supposed to be a maximum, it begins to ascend in a similar curve in the direction *q r*, till it emerges at *r*, where it has recovered during its motion from *p* to *r*, during which the repulsive force accelerates its motion, the velocity which it had lost in its motion from *p* to *q*, during which the repulsive force retarded its motion. It will therefore emerge at *r*, and proceed in the direction *r* S, the reflected ray *r* S making the same angle with the perpendicular GH that the incident ray R *p* did.

The great difficulty in this theory of reflexion, is to understand why only a certain number of the incident rays yield to the repulsive force, while the rest escape from its action; and why the number that are reflected increases with the refractive power of the body. Sir Isaac Newton has endeavoured to explain these facts, as well as many others, by his *Theory of the Fits of easy Reflexion and easy Transmission.* He supposes that light, in its first emission from luminous bodies, is put into fits of easy reflexion and easy transmission; that these fits continue in the rays during their progress; and therefore, that when light is incident on the surfaces of thick transparent bodies, these surfaces reflect those rays which are in fits of easy reflexion, and transmit those which are in fits of easy transmission; and that those surfaces which refract light most strongly when the ray is in a fit of refraction, also reflect it most strongly if the ray is in a fit of reflexion.

The theoretical views of Sir Isaac Newton have been generally adopted by those, who consider light as consisting of material particles projected by the luminous body. The opinion of Newton, and other philosophers, that the space of reflecting activity extends beyond the limits of the space of reflecting activity, has been lately called in question by Dr. Brewster, upon considerations derived from the law of the polarisation of light by reflexion. He supposes that the incident ray has first experienced the influence of the refracting force, and that the reflexion takes place at or near the surface of the body, but at a place nearer the body than the boundary of the space of refracting activity. Upon this principle he explains not only the leading phenomena of the polarisation of light by reflexion, but also the fact, inexplicable on any other supposition, that water reflects more light at great angles of incidence, such as from 78° to 90°, than glass, or even metals. This curious fact, which is put beyond a doubt by the experiments of Bouguer, cannot arise from the superior polish or smoothness of the aqueous surface; for if this were the case, the same effect ought to be produced at smaller angles of incidence; and it is well known, that imperfections in the polish of glass, which are very visible at small angles of incidence, disappear entirely at great angles; and that a piece of rough glass, which will not reflect a single ray of light at an angle of 10°, or 20°, will reflect it most copiously, and will appear perfectly polished, at angles of 70° or 80°.

Having thus explained the Newtonian theory of reflexion, upon the supposition that light consists of material particles emitted from the shining body, we shall now proceed to illustrate the ingenious theory of reflexion as given by Huygens, on the undulatory hypothesis.

Let AB, Fig. 11. be the plane surface of any plate of glass or metal, which we shall suppose at present to be *perfectly polished.* Let AC, inclined to AB, represent a part of a wave of light, whose centre is so remote, that AC may be considered as a straight line. The point C of the wave AC, will, in a certain time, advance to the point B, of the plane AB, by the rectilineal path CB, perpendicular to AC. But in the same time the point A, of the same wave, which is prevented from communicating its motion beyond the plane AB, at least in part, ought to have continued its motion in the ethereal matter, which is above this plane, and through an extent equal to CB, forming its particular spherical wave, in the manner formerly described. (See p. 653.) This particular wave is here represented by the circumference SNR, whose centre is A, and whose radius is AN, equal to CB. In like manner, every other point HH, of the wave AC, will, after its arrival at K, K, form a similar particular wave represented by the circumference of circles, whose centres are K, K, and whose radii are LB, LB. But all these circumferences have for their common tangent the straight line BN, which is a tangent to the first circle SNR. The line BN, therefore, contained between B and the point N, where the perpendicular from the point A falls, being formed by all these circumferences, and terminating the motion which is made by the reflexion of the wave AC, is the point where this motion is also in greater quantity than any where else. It is, therefore, the propagation of the wave AC, at the instant that the point C has arrived in B; for there is no other line which, like BN, is the common tangent to all these circles, excepting BG, below the reflecting plane AB, which would be the propagation of the wave, if the motion had been able to extend itself in a substance homogeneous to that which is above the plane. In order to understand how the wave AC has arrived successively at BN, draw the straight lines KO, KO, parallel to BN; and KL, KL, parallel to AC, and it will be evident that the rectilineal wave AC has been bent in all the lines OKL successively, and has become rectilineal again in BN.

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* These results, obtained by Bouguer, will be given in fuller detail in the second part of this article, when we treat of Photometry.

Now the triangles ACB, BNA, being rectangular, and having the sides AB common, we have, $CB = NA$ the angle $CAB = ABN$ and $ABC = BAN$. But as CB perpendicular to CA is the direction of the incident ray, AN perpendicular to the wave BN, will be the direction of the reflected ray, consequently *the angle of incidence is equal to the angle of reflexion.*

To this demonstration, it may be objected, that though BN is the common tangent to the circular waves in the plane of this figure, yet the waves being in reality spherical, must have an infinite number of similar tangents, viz. all the straight lines which are drawn from the point B in the surface of a cone generated by the revolution of the straight line BN round BA as an axis. In order to show that there is no real difficulty in this, and at the same time to explain the reason why the incident ray is always in the same plane as the reflected ray, and in a plane perpendicular to the reflecting surface, Huygens observes that the wave AC, if considered only as a line, will not produce light. A visible ray of light, he remarks, however small it is, has always some thickness; and in order to represent the wave, the progress of which constitutes a ray, we must substitute in place of a line AC a plane figure, as is shown at HC in Fig. 12. the luminous point being supposed infinitely distant. Now, when every point of the wave HC arrives at the reflecting plane AB, it generates from each point a particular wave of its own; and all these particular waves, when C arrives at B, will have a common plane touching them, viz. a circle BN similar to CH, which will be cut through the middle, and at right angles, by the same plane, which also cuts in a similar manner the circle CH and the ellipse AB.

Hence, it is manifest, that all these spheres of particular waves cannot have another common plane touching them beside the plane BN, so that it is in this plane that there will be much more motion reflected than in any other, and which will therefore carry along the light continued from the wave CH.

Although the motion of the ethereal matter be partly communicated to that of the reflecting body, yet this will in no respect alter the velocity of the waves upon which the equality of the angles of incidence and reflexion depend; for a slight percussion generates in the same medium waves with as great velocity as a stronger percussion, in the same manner as elastic bodies recover their shape in equal times, whether their compression be great or small. The angles of incidence and reflexion will therefore be equal, although the reflecting body may take away part of the motion of the incident light.

Huygens was well aware that the ordinary theory of explaining reflexion by impact against the solid particles of the reflecting body was inconsistent with the phenomena of reflexion, and he therefore has endeavoured to show that a perfectly polished surface is not necessary in his theory, to an equal and regular reflexion. In the theory of undulations, it is supposed that the solid particles of the reflecting body are much larger than those of the ethereal matter, and that the surface consists of particles of matter put together, and small or ethereal particles over and above them. If the reflecting surface, for example, is mercury, Huygens considers its particles as so minute, that we may conceive millions of them in the smallest visible space, arranged like a mass of grains of sand, having its surface smoothed as much as possible. This surface will then become uniform, like that of polished glass, and though it is always rough in relation to the ethereal particles, yet the centres of all the particular spheres of reflected undulations are nearly in the same uniform plane, and their common tangent will touch them as perfectly as is necessary to the production of light; for all that is necessary is, that some of the motion reflected from all points shall not produce any opposite effect.

CHAP. III.

ON CHROMATICS, OR THE DECOMPOSITION OF LIGHT BY PRISMS, AND ITS INFLUENCE ON VISION THROUGH OPTICAL INSTRUMENTS.

In the preceding chapters we have considered light as a simple substance, and have supposed that all its parts or rays had the same properties, and were equally acted upon by the bodies which refracted and reflected them. This, however, though believed to be the case till the time of Sir Isaac Newton, has been completely disproved by his fine experiments with the prism; and we shall therefore proceed to consider the affections and modifications of light, as a compound substance, capable of being decomposed into its elements, and exhibiting in its elementary state new properties of the most interesting kind. In doing this we shall as frequently as possible use the words of Sir Isaac Newton himself, as he seems to have laboured to give the simplest and most convincing views of the various properties which he had established by experiment.

Sect. I.—*On the Colours of Light, and their Different Refrangibilities.*

Prop. I.

The light of the sun consists of rays which differ in colour and refrangibility.

"In a very dark chamber, at a round hole F, Fig. 13. about one-third of an inch broad, made in the shutter of a window, I placed a glass prism ABC, whereby the beam of the sun's light, SF, which came in at that hole, might be refracted upwards, towards the opposite wall of the chamber, and there form a coloured image of the sun, represented at PT. The axis of the prism was, in this and the following experiments, perpendicular to the incident rays. About this axis I turned the prism slowly, and saw the refracted or coloured image of the sun, first to descend, and then to ascend. Between the descent and ascent, when the image seemed stationary, I stopped the prism, and fixed it in that posture, for in that posture the refractions of the light are at the two sides of the refracting angles, that is, at the entrance of the rays into the prism, and at their going out of it, are equal to one another.

Then I let the refracted light fall perpendicularly upon a sheet of white paper, MN, placed at the opposite wall of the chamber, and observed the figure and dimensions of the solar image, PT, formed on the paper by that light. This image was oblong, and not oval, but terminated by two rectilinear and parallel sides, and two semicircular ends. On its sides it was bounded pretty distinctly; but on its ends very indistinctly, the light there vanishing by degrees. At the distance of $18\frac{1}{2}$ feet from the prism the breadth of the image was about $2\frac{1}{8}$ inches, but its length was about $10\frac{3}{4}$ inches, and the length of its rectilinear sides about 8 inches; and ACB, the refracting angle of the prism, by which so great a length was made, was 64 degrees. With a less angle the length of the image was less, the breadth remaining the same. It is also to be observed, that the rays went on in straight lines from the prism to the image, and therefore at their going out of the prism had all that inclination to one another from which the length of the image proceeded. This image PT was coloured, and the more eminent colours lay in this order from the bottom at T to the top at P; *Red*, *Orange*, *Yellow*, *Green*, *Blue*, *Indigo*, *Violet*; together with all their intermediate degrees in a continual succession perpetually varying."

Hence "the light of the sun consists of a mixture of several sorts of coloured rays, some of which at equal incidences are more refracted than others, and therefore are called *more refrangible*. The red at T, being nearest to the place Y, where the rays of the sun would go directly if the prism was taken away, is the least refracted of all the rays; and the *Orange*, *Yellow*, *Green*, *Blue*, *Indigo*, and *Violet*, are continually more and more refracted, as they are more and more diverted from the the course of the direct light. For, when the prism is fixed in the posture above mentioned, so that the place of the image shall be the lowest possible, the figure of the image ought to be round, like the spot at Y, if all the rays that tended to it were equally refracted. Therefore, since it is found that this image is not round, but about five times longer than it is broad, it follows, that all the rays are not equally refracted. This conclusion is farther confirmed by the following experiments.

In the sunbeam SF, Fig. 14. which was propagated into the room through the hole in the window-shutter E G, at the distance of some feet from the hole, I held the prism ABC in such a posture, that its axis might be perpendicular to that beam: then I looked through the prism upon the hole F, and turning the prism to and fro about its axis to make the image *p t* of the hole ascend and descend, when between its two contrary motions it seemed stationary, I stopped the prism; in this situation of the prism, viewing through it the said hole F, I observed the length of its refracted image *p t* to be many times greater than its breadth; and that the *most refracted* part thereof appeared *violet* at *p*; the *least refracted* appeared *red* at *t*; and the *middle* parts *indigo*, *blue*, *green*, *yellow*, and *orange*, in order. The same thing happened when I removed the prism out of the sun's light, and looked through it upon the hole shining by the light of the clouds beyond it. And yet, if the refractions of all the rays were equal according to one certain proportion of the sines of incidence and refraction, as is commonly supposed, the refracted image ought to have appeared round. So then, by these two experiments, it appears that in equal incidences there is a considerable inequality of refractions."

Having discovered this fundamental property of light, he contrived the following experiment, to prove it at sight.

"In the middle of two thin boards DE, *d e*, Fig. 15. I made a round hole in each, at G and *g*, a third part of an inch in diameter; and in the window-shutter a much larger hole being made at F, to let into my darkened chamber a large beam of the sun's light, I placed a prism, ABC, behind the shutter in that beam, to refract it towards the opposite wall; and close behind this prism I fixed one of the boards DE, in such a manner that the middle of the refracted light might pass through the hole made in it at G, and the rest be intercepted by the board. Then, at the distance of about 12 feet from the first board, I fixed the other board *d e*, so that the middle of the refracted light, which came through the hole in the first board, and fell upon the opposite wall, might pass through the hole *g* in this other board *d e*, and the rest being intercepted by the board, might paint upon it the coloured spectrum of the sun. And close behind this board I fixed another prism *a b c*, to refract the light which came through the hole *g*. Then I returned speedily to the first prism ABC, and by turning it slowly to and fro about its axis, I caused the image which fell upon the second board *d e* to move up and down upon that board, that all its parts might pass successively through the hole in that board, and fall upon the prism behind it. And in the mean time I noted the places *M*, *N*, on the opposite wall, to which that light after its refraction in the second prism did pass; and by the difference of the places at *M* and *N*, I found that the light, which, being most refracted in the first prism ABC, did go to the blue end of the image, was again more refracted by the second prism *a b c*, than the light which went to the red end of that image. For when the lower part of the light which fell upon the second board *d e*, was cast through the hole *g*, it went to a lower place M on the wall; and when the higher part of that light was cast through the same hole *g*, it went to a higher place

N on the wall; and when any intermediate part of the light was cast through that hole, it went to some place in the wall between M and N. The unchanged position of the holes in the boards made the incidence of the rays upon the second prism to be the same in all cases. And yet in that common incidence some of the rays were more refracted and others less; and those were more refracted in this prism, which by a greater refraction in the first prism were more turned out of their way; and therefore, for their constancy of being more refracted, are deservedly called *more refrangible.*"

Prop. II.

The light of the sky, or the light of the sun reflected from the first surface of bodies, and also the *white* flames of all combustibles, whether direct or reflected, differ in colour and refrangibility, like the direct light of the sun.

The truth stated in this proposition was established by Newton, by examining all those lights with a prism when they were faint, or transmitting them through the prism, as in Prop. I. when they were sufficiently intense.

Prop. III.

The light of the sun consists of rays differing in reflexibility; and those rays that are more refrangible than others are also more reflexible.

A prism ABC, Fig. 16. whose two angles at its base BC were equal to one another and half right ones, and the third at A a right one, I placed in a beam FM of the sun's light, let into a dark chamber through a hole F, one-third part of an inch broad; and turning the prism slowly about its axis until the light which went through one of its angles ACB, and was refracted by it to G and H, began to be reflected into the line MN by its base BC, at which till then it went out of the glass, I observed that those rays at MH, which had suffered the greatest refraction, were sooner reflected than the rest. To make it evident that the rays which vanished at H were reflected into the beam MN, I made this beam pass through another prism VXY, and being refracted by it to fall afterwards upon a sheet of white paper *p t*, placed at some distance behind it, and there by that refraction to paint the usual colours at *p t*. Then causing the first prism to be turned about its axis according to the order of the letters ABC, I observed, that when those rays M H, which in this prism had suffered the greatest refraction, and appeared *blue* and *violet*, began to be totally reflected, the *blue* and *violet* light on the paper which was most refracted in the second prism received a sensible increase at *p*, above that of the red and yellow at *t*: and afterwards, when the rest of the light, which was *green*, *yellow*, and *red*, began to be totally reflected, and vanished at G, the light of those colours at *t*, on the paper *p t*, received as great an increase as the *violet* and *blue* had received before. Which puts it past dispute, that those rays became first of all totally reflected at the base BC, which before at equal incidences with the rest upon the base BC had suffered the greatest refraction. I do not here take any notice of any refractions made in the sides AC, AB, of the first prism, because the light enters almost perpendicularly at the first side, and goes out almost perpendicularly at the second; and therefore suffers none, or so little, that the angles of incidence at the base BC are not sensibly altered by it; especially if the angles of the prism at the base BC be each about 40°. For the rays FM begin to be totally reflected when the angle CMF is about 50°, and therefore they will then make a right angle of 90° with AC.

"It appears also from experiments, that the beam of light MN, reflected by the base of the prism, being augmented first by the more refrangible rays and afterwards by the less refrangible, is composed of rays differently refrangible.

The light whose rays are all alike refrangible, I call *simple*, *homogeneous* and *similar;* and that whose rays are some more refrangible than others, I call *compound*, *heterogeneous*, and *dissimilar*.

The colours of homogeneous lights I call *primary*, *homogeneous* and *simple;* and those of heterogeneous lights, *heterogeneous* and *compound*. For these are always compounded of homogeneous lights.

The homogeneous lights and rays which appear red, or rather make objects appear so, I call *red-making;* those which make objects appear yellow, green, blue, and violet, I call *yellow making*, *blue making*, *violet making;* and so of the rest. And if at any time I speak of light and rays as coloured, or endowed with colours, I would be understood to speak not philosophically. For the rays, to speak properly, are not coloured, and in them there is nothing else than a certain power and disposition to a sensation of this or that colour."

Prop. IV.

To separate from one another the heterogeneous rays of compound light.

"That the rays which are equally refrangible fall upon a circle answering to the sun's apparent disk, will be proved by experiment by and by.

Let AG, Fig. 17. represent the circle which all the most refrangible rays, propagated from the whole disk of the sun, will illuminate and paint upon the opposite wall if they were alone; EL the circle, which all the least refrangible rays would in like manner illuminate if they were alone; BH, CI, DK, the circles which so many intermediate rays would paint upon the wall, if they were singly propagated from the sun in successive order, the rest being intercepted; and conceive that there are other circles without number, which innumerable other intermediate sorts of rays would successively paint upon the wall, if the sun should successively emit every sort apart. And seeing the sun emits all these sorts at once, they must all together illuminate and paint innumerable equal circles; of all which being, according to their degrees of refrangibility, placed in order in a continual series, that oblong spectrum PT is composed, which was described in the first experiment.

Now, if these circles, whilst their centres keep their distances and positions, could be made less in diameter, their interfering one with another, and consequently the mixture of the heterogeneous rays, would be proportionably diminished. Let the circles AG, BH, CI, &c. remain as before; and let *a g*, *b h*, *c i*, &c. be so many less circles lying in a like continual series, between two parallel right lines *a e*, and *g l*, with the same distance between their centres, and illuminated with the same sorts of rays; that is, the circle *a g* with the same sort by which the corresponding circle AG was illuminated; and the rest of the circles *b h*, *c i*, *d k*, *e l*, respectively with the same sorts of rays by which the corresponding circles BH, CI, DK, EL, were illuminated. In the figure PT, composed of the great circles, three of those, AG, BH, CI, are so expanded into each other, that three sorts of rays, by which those circles are illuminated, together with innumerable other sorts of intermediate rays, are mixed at QR in the middle of the circle BH. And the like mixture happens throughout almost the whole length of the figure PT. But in the figure *p t*, composed of the less circles, the three less circles *a g*, *b h*, *c i*, which answer to those three greater, do not extend into one another; nor are there any where mingled so much as any two of the three sorts of rays by which those circles are illuminated, and which in the figure PT are all of them intermingled at QR. So then, if we would diminish the mixture of the rays, we are to diminish the diameters of the circles. Now these would be diminished if the sun's diameter, to which they answer, could be made less than it is, or (which comes to the same purpose) if without doors, at great distance from the prism towards the sun, some opaque body were placed with a round hole in the middle of it to intercept all the sun's light, except so much as coming from the middle of his body could pass through that hole to the prism. For so the circles AG, BH, and the rest, would not any longer answer to the whole disk of the sun, but only to that part of it which could be seen from the prism through that hole; that is, to the apparent magnitude of that hole viewed from the prism. But that these circles may answer more distinctly to that hole, a lens is to be placed by the prism to cast the image of the hole (that is, every one of the circles AG, BH, &c.) distinctly upon the paper at PT: after such a manner as by a lens placed at a window the pictures of objects abroad are cast distinctly upon a paper within the room. If this be done, it will not be necessary to place that hole very far off, no, not beyond the window. And therefore, instead of that hole, I used the hole in the window shutter as follows.

In the sun's light let into my darkened chamber through a small round hole, Fig. 18, in my window-shutter, at about 10 or 12 feet from the window, I placed a lens MN, by which the image of the hole F might be distinctly cast upon a sheet of white paper placed at I. Then immediately behind the lens I placed a prism ABC, by which the trajected light might be refracted either upwards or sidewise, and thereby the round image which the lens alone did cast upon the paper at I, might be drawn out into a long one with parallel sides, as represented at *p t*. This oblong image I let fall upon another at about the same distance from the prism as the image at I, moving the paper either towards the prism or from it, until I found the just distance where the rectilinear sides of the images *p t* become most distinct. For in this case the circular images of the hole, which compose that image, after the manner that the circles *a g*, *b h*, *c i*, &c. do the figure *p t*, were terminated most distinctly, and therefore extended into one another the least that they could, and by consequence the mixture of the heterogeneous rays was now the least of all. The circles *a g*, *b h*, *c i*, &c. which compose the image *p t*, are each equal to the circle at I; and therefore, by diminishing the hole F, or by removing the lens farther from it, may be diminished at pleasure, whilst their centres keep the same distances from each other. Thus, by diminishing the breadth of the image *p t*, the circles of heterogeneal rays that compose it may be separated from each other as much as you please. Yet instead of the circular hole F, it is better to substitute an hole shaped like a parallelogram, with its length parallel to the length of the prism. For if this hole be an inch or two long, and but a tenth or twentieth part of an inch broad, or narrower, the light of the image *p t* will be as simple as before, or simpler; and the image being much broader, is therefore fitter to have experiments tried in its light than before."

Prop. V.

"Homogeneal light is refracted regularly without any dilatation, splitting or shattering of the rays; and the confused vision of objects seen through refracting bodies by heterogeneous light, arises from the different refrangibility of several sorts of rays.

In the middle of a black paper I made a round hole, about a fifth or a sixth part of an inch in diameter. Upon this part I caused the spectrum of homogeneous light, described in the former proposition, so to fall that some part of the light might pass through the hole in the paper. This transmitted part of the light I refracted with a prism placed behind the paper: and letting the refracted light fall perpendicularly upon a white paper two or three feet distant from the prism, I found that the spectrum formed on the paper by this light was not oblong, as when it is made in the first experiment, by refracting the sun's compound light, but was, so far as I could judge by my eye, perfectly circular, the length being nowhere greater than the breadth; which shows that this light is refracted regularly without any dilatation of the rays, and is an ocular demonstration of the mathematical proposition mentioned above.

In the homogeneous light I placed a paper circle of a quarter of an inch in diameter: and in the sun's unrefracted, heterogeneous, white light, I placed another paper circle of the same bigness; and going from these papers to the distance of some feet, I viewed both circles through a prism. The circle illuminated by the sun's heterogeneous light appeared very oblong, as in the second experiment, the length being many times greater than the breadth. But the other circle, illuminated with homogeneous light, appeared circular, and distinctly defined, as when it is viewed by the naked eye; which proves the whole proposition mentioned above.

In the homogeneous light I placed flies and other minute objects, and viewing them through a prism, I saw their parts as distinctly defined as if I had viewed them with the naked eye. The same objects placed in the sun's unrefracted heterogeneous light, which was white, I viewed also through a prism, and saw them most confusedly defined, so that I could not distinguish their smaller parts from one another. I placed also the letters of a small print one while in the homogeneous light, and then in the heterogeneous; and viewing them through a prism, they appeared in the latter case so confused and indistinct that I could not read them; but in the former they appeared so distinct that I could read readily, and thought I saw them as distinct as when I viewed them with my naked eye: in both cases, I viewed the same objects through the same prism, at the same distance from me, and in the same situation. There was no difference but in the lights by which the objects were illuminated, and which in one case was simple, in the other compound; and therefore the distinct vision in the former case, and confused in the latter, could arise from nothing else than from that difference in the lights. Which proves the whole proposition.

In these three experiments, it is farther very remarkable, that the colour of homogeneous light was never changed by the refraction. And as these colours were not changed by refractions, so neither were they by reflexions. For all white, grey, red, yellow, green, blue, violet bodies, as *paper*, *ashes*, *red lead*, *orpiment*, *indigo*, *bice*, *gold*, *silver*, *copper*, *grass*, *blue flowers*, *violets*, *bubbles of water tinged with various colours*, *peacock feathers*, the tincture of *lignum nephriticum*, and such like, in red homogeneous light appeared totally red, in blue light totally blue, in green light totally green, and so of other colours. In the homogeneous light of any colour they all appeared totally of that same colour; with this only difference, that some of them reflected that light more strongly, others more faintly. I never yet found any body which by reflecting homogeneous light could sensibly change its colour.

From all which it is manifest, that if the sun's light consisted of but one sort of rays, there would be but one colour in the world, nor would it be possible to produce any new colour by reflexions and refractions; and, by consequence, that the variety of colours depends upon the composition of light."

Prop. VI.

"Every homogeneous ray considered apart is refracted, according to one and the same rule; so that its sine of incidence is to its sine of refraction in a given ratio: that is, every differently coloured ray has a different ratio belonging to it.

Sir Isaac Newton has proved this by experiment; and in other experiments he has determined by what numbers these given ratios are expressed. For instance, if an heterogeneous white ray of the sun emerges out of glass into air; or, which is the same thing, if rays of all colours be supposed to succeed one another in the same line AC, Fig. 19. and AD their common sine of incidence in glass be divided into *fifty* equal parts, then EF and GH, the sines of refraction into air, of the least and most refrangible rays, will be 77 and 78 of such parts respectively. And since every colour has several degrees, the sines of refraction of all the degrees of red will have all intermediate degrees of magnitude from 77 to $77\frac{1}{8}$;—of all the degrees of orange from $77\frac{1}{8}$ to $77\frac{1}{5}$;—of yellow from $77\frac{1}{2}$ to $77\frac{2}{3}$;—of green from $77\frac{1}{3}$ to $77\frac{1}{2}$;—of blue from $77\frac{1}{2}$ to $77\frac{2}{3}$;—of indigo from $77\frac{2}{3}$ to $77\frac{7}{9}$;—and of violet from $77\frac{7}{9}$ to 78.

Prop. VII.

Whiteness, and all grey colours between white and black, may be compounded of colours; and the whiteness of the sun's light is compounded of all the primary colours, mixed in a due proportion.

"Let that spectrum or solar image PT, in Fig. 20. fall upon the lens MN, above four inches broad, and about six feet distant from the prism ABC, and so figured that it may cause the coloured light which divergeth from the prism to converge and meet again at its focus G, about six or eight feet distant from the lens, and there to fall perpendicularly upon a white paper DE. And if you move this paper to and fro, you will perceive that near the lens, as at *d e*, the whole solar image (suppose at *p t*) will appear upon it intensely coloured after the manner above explained, and that by receding from the lens those colours will perpetually come towards one another, and by mixing more and more, dilute one another continually, until at length the paper come to the focus G, where, by a perfect mixture, they will wholly vanish and be converted into whiteness, the whole light appearing now upon the paper like a little white circle. And afterwards, by receding farther from the lens, the rays which before converged will now cross one another in the focus G, and diverge from thence, and thereby make the colours to appear again, but yet in a contrary order; suppose at $\delta\,\varepsilon$, where the red *t* is now above which before was below, and the violet *p* is below which before was above.

Let us now stop the paper at the focus G, where the light appears totally white and circular, and let us consider its whiteness. I say, that this is composed of the converging colours. For if any of those colours be intercepted at the lens, the whiteness will cease and degenerate into that colour which ariseth from the composition of the other colours which are not intercepted. And then if the intercepted colours be let pass and fall upon that compound colour, they mix with it, and by their mixture restore the whiteness. So if the violet, blue, and green be intercepted, the remaining yellow, orange, and red, will compound upon the paper an orange, and then if the intercepted colours be let pass they will fall upon this compounded orange, and together with it decompound a white. So also if the red and violet be intercepted, the remaining yellow, green, and blue, will compound a green upon the paper, and then the red and violet being let pass, will fall upon this green, and together with it decompound a white. And that in this composition of white the several rays do not suffer any change in their colorific qualities by acting upon one another, but are only mixed, and by a mixture of their colours produce *white*, may farther appear by these arguments.

If the paper be placed beyond the focus G, suppose at $\delta\,\varepsilon$, and then the red colour at the lens be alternately intercepted, and let pass again, the violet colour on the paper will not suffer any change thereby, as it ought to do if the several sorts of rays acted upon one another in the focus G, where they cross. Neither will the red upon the paper be changed by any alternate stopping, and letting pass the violet which crosseth it.

And if the paper be placed at the focus G, and the white round image at G be viewed through the prism

HIK, and by the refraction of that prism be translated to the place r v, and there appear tinged with various colours, namely, the violet at v and red at r, and others between, and then the red colour at the lens be often stopped and let pass by turns, the red at r will accordingly disappear, and return as often, but the violet at v will not thereby suffer any change. And so by stopping and letting pass alternately the blue at the lens, the blue at r will accordingly disappear and return, without any change made in the red at r. The red therefore depends on one sort of rays, and the blue on another sort, which in the focus G, where they are commixed, do not act on one another. And there is the same reason of the other colours.

I considered farther, that when the most refrangible rays P p, and the least refrangible ones T t, are by converging inclined to one another, the paper, if held very oblique to those rays in the focus G, might reflect one sort of them more copiously than the other sort, and by that means the reflected light would be tinged in that focus with the colour of the predominant rays, provided those rays severally retained their colours or colorific qualities in the composition of white made by them in that focus. But if they did not retain them in that white, but became all of them severally endued there with a disposition to strike the sense with the perception of white, then they could never lose their whiteness by such reflexions. I inclined therefore the paper to the rays very obliquely, as in the second experiment of this book, that the most refrangible rays might be more copiously reflected than the rest, and the whiteness at length changed successively into blue, indigo, and violet. Then I inclined it the contrary way, that the most refrangible rays might be more copious in the reflected light than the rest, and the whiteness turned successively to yellow, orange, and red.

Lastly, I made an instrument XY, in fashion of a comb, whose teeth were about an inch and an half broad, and the intervals of the teeth about two inches wide. Then by interposing successively the teeth of this instrument near the lens, I intercepted part of the colours by the interposed tooth, whilst the rest of them went on through the interval of the teeth to the paper DE, and there painted a round solar image. But the paper I had first placed so, that the image might appear white as often as the comb was taken away; and then the comb being, as was said, interposed, that whiteness by reason of the intercepted part of the colours at the lens did always change into the colour compounded of those colours which were not intercepted, and that colour was by the motion of the comb perpetually varied, so that in the passing of every tooth over the lens all these colours, red, yellow, green, blue, and purple, did always succeed one another. I caused therefore all the teeth to pass successively over the lens, and when the motion was slow, there appeared a perpetual succession of the colours upon the paper: But if I so much accelerated the motion, that the colours by reason of their quick succession could not be distinguished from one another, the appearance of the single colours ceased. There was no red, no yellow, no green, no blue, nor purple, to be seen any longer, but from a confusion of them all there arose one uniform white colour. Of the light which now by the mixture of all the colours appeared white, there was no part really white. One part was red, another yellow, a third green, a fourth blue, a fifth purple, and every part retains its proper colour till it strike the sensorium. If the impressions follow one another slowly, so that they may be severally perceived, there is made a distinct sensation of all the colours, one after another, in a continual succession. But if the impressions follow one another so quickly that they cannot be severally perceived, there ariseth out of them all one common sensation, which is neither of this colour alone nor of that alone, but hath itself indifferently to them all, and this is a sensation of whiteness.

Prop. VIII.

If a *small* aperture is viewed through a prism, or if the sun's light passing through a small aperture falls upon a prism, the spectrum thus produced contains only four colours.

In the spectrum seen by Sir Isaac Newton, and formed from the sun's disc, the colours are arranged as in Fig. 1. of Plate CCCCXXXIII. and occupy the respective spaces represented in that figure. But when a beam of day light is admitted into a room by a crevice about $\frac{1}{26}$th of an inch wide, and received by the eye at the distance of 10 or 12 feet, through a prism ABC, Fig. 2. of flint glass, free from veins, and held near the eye, so that the angles RAB, RAC, formed by the incident rays with the sides of the prism, are equal, the beam will be refracted into the four following colours only, viz. *Red*, *yellowish Green*, *Blue*, and *Violet*, as represent at MN. The line A, which bounds the red end of the spectrum, is somewhat confused. The line B, which separates the red and the green spaces, is perfectly distinct in a certain position of the prism, and so are the bounding lines of the violet space at D and E. The boundary C of green and blue is less distinctly marked than the rest; and on each side of this line there are other *distinct dark lines* f and g, either of which may be mistaken by an inexperienced observer for the boundary C. The proportions of the coloured spaces have already been stated in the History of Optics.*

Scholium.

The very important discovery contained in this proposition was made by Dr. Wollaston; and it decidedly follows from it, that the other colours in the spectrum described by Newton are *compound tints*, and have refrangibilities the same as some other rays in the Newtonian spectrum. The *yellow* rays, for example, in the Newtonian spectrum, have the same refrangibility as some of the *green*, and also some of the *red* rays in the same spectrum, and their apparent existence as separate rays arises entirely from the analysis not being complete, in consequence of too large an aperture having been used.

From these experiments Dr. Wollaston and Dr. Young have concluded, that the *yellow rays have not a separate existence in the spectrum*. Dr. Young, who repeated Dr. Wollaston's experiments with perfect success, remarks that there is a *narrow yellow line* generally visible at the limit of the *red and green*, but that its breadth scarcely exceeds that of the aperture by which the light is admitted, and that Dr. Wollaston attributes it to the *mixture of the red with the green light.*[*]

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* See p. 615, and also p. 606. See likewise the *Phil. Trans.* 1802, or *Nicholson's Journal*, 8vo. vol. iv. p. 89.

Dr. Brewster has however recently shown,[†] that the yellow rays have a separate and independent existence in the spectrum, formed in the manner described by Dr. Wollaston, and that they are only mixed with the most refrangible red and the least refrangible green, with which they have the same refrangibility. By the use of coloured media which absorb these two kinds of rays, he has been able to insulate the yellow space, so as to establish its existence beyond a doubt.

Def. When a pencil of white light is separated into its component colours, it is said to be *dispersed* by the prism; that is, the extreme red and the extreme violet rays are dispersed or separated from the middle rays of the spectrum. The dispersion is generally measured by the part of the whole refraction to which it is proportional. If a prism of crown glass, for example, produces a deviation in the mean ray of 27°, the *dispersion*, or the angle formed by the extreme red and the extreme blue rays, will be 1°; that is, the deviation of the red rays will be 26° 30′, that of the mean or green rays 27°, and that of the extreme violet 27° 30′. The dispersion is therefore said to be $\frac{1}{27}$th of the whole refraction, and this fraction is a measure of the *dispersive power*. We must, however, carefully distinguish between the *dispersion* of any substance and its *dispersive power*, which, though often confounded, differ as essentially as the *refraction* of any substance does from its *refractive power*. The dispersion varies in the same substance with the angle of the prism which decomposes the light, and is merely used to signify the actual separation of the extreme rays, while the dispersive power is the ratio of that separation to the whole refraction.

Prop. IX.

To determine the nature and magnitude of the imperfections of refracting telescopes and other instruments arising from the different refrangibility of the rays of light.

Let MN, Fig. 3. be a lens, on which are incident the parallel rays RM, RN of white light. In consequence of the different refrangibility of the rays of which this light is composed, each ray will be refracted to different parts of the axis, the extreme violet ray being refracted in the lines ML, NL, and the extreme red ray in the lines MF, NF. Every differently coloured ray, therefore, will form a different image of the object from which the white rays RM, RN diverge, and as these images do not coincide, but occupy different positions between L and F, the image formed behind the glass must be confused and indistinct. Hence, as all refracting telescopes and microscopes, and the eye-glasses of all reflecting telescopes and microscopes, consist of lenses, these instruments must all be rendered imperfect by the different refrangibility of light.

In order to find the amount of this imperfection, and the form of the space of diffusion LA *a* F, and the distribution of the light in different parts of it, we shall suppose LF known, as it is easily derived from the ratio of the angle of dispersion MF, to the whole refraction ECM of the mean refrangible ray, which is in ordinary glass as 1 to 27. As the angles FN *a*, FMA are small, the sides LA, L *a* may be considered as parallel to the sides FA, F *a*, and therefore LA, F *a* may be regarded as a parallelogram divided into two equal parts by the diagonal A *a*. But CF : EF = A *a* : MN, and alternately CF : A *a* = EF : MN, and LF = 2 CF : A *a* = 2 EF : MN; that is, the *longitudinal aberration of refrangibility*, or LF, *is to the lateral aberration or the diameter of the circle of diffusion* A *a*, *as twice the focal distance is to the aperture.*

With regard to the distribution of the light in the circle of diffusion, represented in Fig. 4, where the diameter A *a* corresponds to A *a* in Fig. 3. and the points I, *i*, to the same points in Fig. 4. Boscovich has shown, as Newton had done before, that if the point N is equidistant from A and C, the density of the rays in any point B will be to the density in any point N as AB : BC; and that the whole light within the lesser circle B *b*, will be to the whole light within the circle A *a*, as the difference of the squares of CA, AB is to the square of CA.[‡] If BC, for example, is one-fifth of AC, the light will be four times denser in B than in N, and the whole light within the lesser circle B *b* will be to the whole light within the greater circle as 9 to 25. The intensity of the light will therefore diminish very rapidly towards the circumference of A *a*, where it is infinitely rare, and, consequently, a very luminous image will be formed near the centre C of the space LF, the eye being but little distracted with the other faint images around it.

Prop. X.

Different bodies possess different powers of dispersing the rays of light.

Let several prisms be made out of different solid and fluid substances, and the prismatic spectrum be formed, in the manner described in the preceding experiments. Measure the length of the spectrum as produced by the prisms, and compute the angle which it subtends, by measuring its distance from the prism. The number of times that this angular magnitude is contained in the angle of deviation for the mean, or middle ray of the spectrum, as found by Prop. IX. p. 634, will give the dispersive power of the prism, which will be found to vary with different substances.

The same experiment may be made in a simpler manner, by taking two prisms of crown and flint glass, for example, which have such refracting angles as to give equal angles of deviation, or produce equal and opposite refractions. When this is the case, it will be found that the object, though not displaced by refraction, is still highly tinged with colour, and that the colours will have the same position as if they had been formed by a small prism placed similarly to the prism of flint glass.

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[*] See Dr. Young's *Natural Philosophy*, vol. i. p. 438 and p. 786, Fig. 419, also vol. ii. p. 637.

[†] *Edinburgh Transactions*, vol. ix. part. ii.

[‡] A very simple demonstration of this, for which we cannot find room, will be found in Boscovich's *Opera*, &c. tom. ii. p. 233—236. See also Newton's *Optics*, p. 85.

The most extensive series of experiments on the dispersive powers of bodies, are those made by Dr. Brewster with a new instrument, in which the dispersive power of any prism is measured by correcting its colour with a standard prism, whose refracting angle is made to vary in reference to a given line, by giving it a rotatory motion in a plane which bisects the refracting angle.

In order to explain this, let AO, BO, CO, DO, EO, &c. Fig. 5. be a number of black lines, forming equal angles, AOB, BOC, &c. and let them be viewed by a prism, having the common section of its refracting planes parallel to CG, or perpendicular to AE. Then, since the refraction is made in the direction EA, the line CG will be more tinged with colour at its edges than any of the other lines, the red and yellow colour being on the right, and the blue and violet on the left of the line. The lines BF and DH will be tinged with less colour, while the line AE will appear without the least degree of colour at its edges. If the prism is now turned round in the plane which bisects the refracting angle, till the common section of the refracting planes is parallel to DH, and perpendicular to BF, the refraction will be made in the direction BF; the line DH will be coloured in the same manner as CG was coloured before; CG and AE will have the same colour that BF had formerly, while BF will be completely unaffected with colour. In like manner, by continuing to turn the prism in the same plane, till the common section of its refracting surfaces is successively perpendicular to CG and DH, the lines CG and DH will be free of any prismatic tinge. Hence it follows, that in giving a rotatory motion to a prism in the plane which bisects its refracting angle, there is always one line in reference to which there is neither refraction nor colour, and that this line is perpendicular to another line, in which the refraction and colour are a maximum. While the prism, therefore, performs ¼th of a revolution, its refracting angle may be considered as having varied from 0° to the real angle of its refracting surfaces. Thus in Fig. 6. let ABCDE be a prism, ABCD one of its refracting surfaces, ADE its refracting angle, and CD the common section of its refracting planes. From any point O, draw O *b* parallel to CD, and O *d* perpendicular to O *b*. Then it is obvious, that in the direction O *b* the refracting angle of the prism may be considered as 0, while in the direction O *d* the refracting angle is equal to ADE; and in any intermediate direction O *c*, the refracting angle, will be equal to Sin. *b* O *c* × ADE, or Cos. *c* O *d* × ADE.

In applying this principle to the measurement of refractive and dispersive powers, it is necessary to have a standard prism of flint-glass, or crown-glass, the refracting angle, and the refractive and dispersive powers of which have been accurately determined. Another prism, composed of two parallel planes of glass, but with a much smaller refracting angle, must also be constructed for holding the different fluids that are to be subjected to examination. The second of these prisms must be fixed upon the ring OO, at the end of the arm G of the goniometer, (see GONIOMETER, Plate CCLXXVII. Fig. 13.) or any other circular instrument with an open centre, so as to remain stedfast in that position. The standard prism must be fixed to the ring at the centre of the circle AB, nearer the eye of the observer, and in such a manner that the two prisms may refract in opposition, and that the index E may point to zero, (the scale beginning at 90°,) when the common section of the refracting planes of the one is parallel to the common section of the refracting planes of the other. In this situation, the greatest refracting angle of the one is exactly opposed to the greatest refracting angle of the other. Let the common section of the refracting planes be in a vertical line, and let the observer view through the combined prisms a vertical line AB, Fig. 7. upon a light ground, like the bar of a window seen against the sky. Since the refraction of the standard prism is supposed to be greater than that of the fixed prism, the refracted image A′B′ of the object AB will appear separated from the object AB. Let the standard prism, therefore, be turned round by means of the finger screw Q, till the refracted image A′B′ comes into the position *a b*, and coincides exactly with the object AB, and let the degrees and minutes pointed out by the index be carefully marked. Then, if A be the greatest angle of the standard prism, and M the arch pointed out by the index, we shall have Sin. M × A for the reflecting angle of the prism, when the direct and refracted images were coincident. Since the refracting angle, therefore, of both prisms, and the refractive power of the standard prism, are known, the refractive power of the substance included in the fixed prism may be found, from the formulæ to be afterwards given.

If the sides of the rectilineal object AB are free from colour when the coincidence takes place, then the standard prism has the same dispersive power as the substance in the fixed prism, provided their refractive power be the same; for, at the same angle of refraction, the dispersion of the fixed prism is exactly corrected by that of the standard prism. If the sides of the object, however, are tinged with colour, turn round the standard prism in the same direction as before, and if the colour increases, the dispersive power of the fixed prism exceeds that of the standard one; if, on the contrary, the colour diminishes, the dispersive power of the standard prism exceeds that of the fixed one. In order to find the real dispersive power of the fixed prism, turn the standard prism till the vertical line is completely free from colour, and let *m* be the angle pointed out by the index. The refracting angle of the standard prism, which corrects the colour of the fixed prism, will then be Sin. *m* × A, from which the dispersive power of the substance contained in the fixed prism may be readily deduced. In these experiments, the fixed prism must be placed in such a position with respect to the object AB, that a line joining the object and the prism may be perpendicular to the first refracting surface, which may be easily effected by the most simple contrivances. By this means the incident rays will suffer no refraction at the first surface, and the formulæ for finding the refractive and dispersive powers of the fixed prism, will be much less complicated than if the refraction at the first surface had been introduced. The following formulæ, which are very simple, are nearly the same with those which were given by Boscovich.

Angle of the fixed prism	A
Angle of the variable prism, (or Sin. M × A′A, A′ being the refracting angle of the variable prism,) by which the refraction of the fixed prism is corrected	a
Angle of the variable prism (or Sin. *m* × A′) which corrects the dispersion of the fixed prism .	α
Index of refraction of the fixed prism . .	R

Index of refraction of the variable prism . . r
The portion of the mean refraction to which the dispersion is equal $d\,\mathrm{R}$, $d\,r$
The dispersive power of the fixed prism $\mathrm{D} = \frac{d\,\mathrm{R}}{\mathrm{R}-1}$

Then for the refractive power we shall have

$$\text{Sin.}\,\overline{a - x} = \frac{\text{Sin.}\,\overline{a - \mathrm{A}}}{\mathrm{R}}.$$

The sine of $a - x$ being found from this formula, the sine of x may be easily found. We shall then have

$$\mathrm{R} = \frac{r \times \text{Sin.}\,x}{\text{Sin. A}}.$$

When the prisms do not differ much from each other in refractive power, such as prisms made of different kinds of glass, the following more simple formulæ may be used. Thus, make

$$p = a - \mathrm{A}; \text{ and } q = p - \frac{p}{r}, \text{ then}$$

$$\mathrm{R} = r + r\ \text{Sin.}\,q\ \text{Cot. A}.$$

In order to find the dispersive power of the fixed prism, we have

$$\text{Sin.}\,x' = \frac{\mathrm{R}}{r} \times \text{Sin. A};$$

and when x' is thus found, we have

$$\frac{d\mathrm{R}}{d\,r} = \frac{\mathrm{R}}{r} \times \text{Tang.}\,\overline{\alpha - x'} \times \text{Cot.}\,x' + 1,$$

$$d\mathrm{R} = dr \times \frac{\mathrm{R}}{r} \times \text{Tang.}\,\overline{\alpha - x'} \times \text{Cot.}\,x' + 1, \text{ and}$$

$$\mathrm{D} = \frac{\frac{\mathrm{R}}{d\,r \times r} \times \text{Tang.}\,\overline{\alpha - x'} \times \text{Cot.}\,x' + 1}{\mathrm{R} - 1},$$

R being the index of refraction for the mean refrangible rays, dR is a part of the whole refraction, and is always equal to the difference between the index of refraction for the first red ray, and the index of refraction for the last violet ray.

In measuring the dispersive powers of different kinds of flint or crown glass, by means of a standard prism of the same glass, or in every case where R is nearly equal to r, we have $x' = \mathrm{A}$; and therefore the formula may be greatly simplified, and will then become

$$\mathrm{D} = \frac{d\,r \times \text{Tang.}\,a - \mathrm{A} \times \text{Cot. A} + 1}{\mathrm{R} - 1}.$$

If it should happen that the fixed prism contained a substance of such a high refractive or dispersive power, that the greatest angle of the standard prism was incapable of correcting its refraction and dispersion, the standard prism may then be fixed in the place of the other, while the other prism has its refracting angle reduced by a rotatory motion, till it corrects the refraction and dispersion of the standard prism; but in this case the emergent ray must be perpendicular to the surface n next the eye; and when necessary to prevent total reflexion at the surface n, a parallel plate of any fluid may be introduced between the prisms.

In order to increase the accuracy of these observations, the goniometer containing the two prisms might be placed before the object-glass of a small telescope through which the observer must examine the object AB, and its fringes of colour. By this means the fringes will be greatly magnified, and the position of the standard prism, when the refracted image of AB is perfectly achromatic, will afford a measure of the angle to which it has been reduced.

The subject of dispersive powers has, till within these few years, been investigated merely for the purpose of discovering achromatic combinations for the improvement of the telescope. The dispersions of two or three different kinds of glass, and of a few fluids, were numerically ascertained; but no attempt was made to consider the subject in a general manner, or to investigate it as a separate branch of science, exhibiting the most curious results, and unfolding new properties of transparent bodies. Dr. Wollaston had the honour of beginning this important inquiry; and he determined the order of dispersive powers for 33 substances, without, however, giving any numerical estimate of their magnitude. By means of the instrument which has been briefly described, Dr. Brewster has ascertained, in numbers, the dispersive powers of more than a hundred transparent substances, the greater part of which were never before examined.

The instrument which was employed in these experiments, is represented in section in Fig. 8. The circular head AB, similar to that which is shown in the article Goniometer, Plate CCLXXVII. Fig. 13. is divided into 360 degrees; and has a tubular shoulder, e, e, which moves upon the tube $d\,d'$, $d\,d'$. Upon the tube $d\,d'$, $d\,d'$, is fixed another small tube, that carries the the arm $d\,c$, on the circumference of which is the vernier scale for subdividing the degrees on the circular head. The extremity $d\,d$ of the tube $d\,d'$, $d\,d'$ is fixed into the stand CD, and upon its other extremity $d'\,d'$, which terminates in a ring, is fixed the prism m, whose dispersive power is required. The standard prism n, having such a refracting angle as to produce a greater dispersion than that of m, is fastened to a tube $f\,g$, which screws upon the outer surface of the shoulder $e\,e'$. It is obvious, from the preceding description, that when the circular head AB is turned round, the tube $f\,g$, with the standard prism n, will be carried along with it, while the vernier c and the other prism m remain stationary: and if the inner surfaces of the two prisms were parallel to each other, and perpendicular to the axis of motion, in any given position of the circular head, this parallelism will be preserved in every other position.

A horizontal bar AB,* Fig. 9. about three or four inches broad, and having its sides perfectly straight and parallel, is stretched across the window, so as to be exactly perpendicular to a plumb line CD suspended from the top of the window. The instrument is then placed at a convenient distance from the bar, and in such a position that a line joining the eye of the observer at O, Fig. 8. and the centre of the bar at E, Fig 12. may be perpendicular to the anterior surface of the prism m, and to the bar AB. When this adjustment is made, the whole of the instrument is turned round in the tube which forms the top of the stand, till the common section of the refracting surfaces of the prism m is perpendicular to CD, and it is fixed in this position by the screw at s. If the bar AB be now viewed through the prism m, the lower side of it will be bordered with red and yellow, and the upper side with blue and violet; but after the tube fg, with the standard prism n, is screwed upon the shoulder $e\,e'$, so as to refract in opposition to m, with the common section of its planes turned upwards, and perpendicular to CD, the red and yellow fringes will appear on the upper side of AB, while the blue and violet fringes occupy its lower side, on account of the superior dispersion produced by the standard prism. In order to diminish the refracting angle of the prism n, turn round the circular head AB towards the right hand, the eye continuing to observe the image of the bar, AB, Fig. 9. and the coloured fringes will gradually diminish. As soon as the fringes vanish, and the bars appear completely free from colour, mark the degree and minute of the circular head which is indicated by the vernier. Turn the circular head towards the left hand, till the fringes again disappear, and mark the degree and minute pointed out by the index. Then if ϕ be the arch comprehended between these two positions, and B the angle of the standard prism n, the refracting angle α, to which this prism has been reduced in order to correct the dispersion of the prism m, will be obtained from the following formula, viz.

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* If AB were a rectangular luminous space, placed on a dark ground, it would answer the purpose equally well.

$$\alpha = \text{Cos.}\,\frac{\phi}{2} \times \text{B}.$$

Thus if the prism m has an angle of 24° 39′, and contains water, and if n is a prism of flint glass, we shall have $\phi = 156°$ when B is equal to 41° 11′, and consequently $\alpha = \text{Cos. } 78° \times 41°\ 11' = 8°\ 34'$, that is, a prism of flint glass of 8° 34′ corrects the dispersion of a prism of water of 24° 39′. Hence, if the refractive power of water is known, and also the refractive and dispersive powers of flint glass, the dispersive power of water may be determined from the formula in page 686. As an example of this calculation, we shall take the case of *Water* and *Flint glass*.

Angle of the prism of *Water*	$24°\ 39 = \text{A}$
Angle of the prism of *Flint glass* . . .	$41°\ 11' = \text{B}$
Reduced angle of the prism of flint glass, which corrects the dispersion of the prism of water	$8°\ 34' = \alpha$
Refractive power of the prism of flint glass .	$1\,616 = \text{R}$
Refractive power of water	$1\,336 = r$
The portion of the mean refraction of flint glass to which the dispersion is equal . . .	$0.0320 = dr$

$$\begin{array}{ll}
\text{R} = 1.336\ .\ \text{Log.} & 0.125806 \\
r = 1.616\ .\ \text{Log.} & 0.208441 \\
\hline
\frac{\text{R}}{r}\quad .\quad . & 9.917365 \\
\text{Sin. A} = 24°\ 39' & 9.620213 \\
\hline
\text{Sin. } x' = 20°\ 10' & 9.537578 \\
\hline
\end{array}$$

$$\begin{array}{l}
\alpha = 8°\ 34' \\
x' = 20°\ 10' \\
\hline
\overline{-\alpha - x'}\ 11°\ 36'
\end{array}$$

$$\begin{array}{ll}
\text{Cotangent of } x' & 10.435017 \\
\text{Tangent of } \alpha - x' & 9\,312327 \\
\hline
-0.5589 & 9.747344 \\
+1. & \\
\hline
.4411 & 9.644537 \\
\times \frac{\text{R}}{r} & 9.917365 \\
\times\, d\,r & 8.505150 \\
\hline
d\,\text{R} = 0.0117 & 8\,067052 \\
\text{R} - 1 = .336 & 9.526339 \\
\hline
\frac{d\,\text{R}}{\text{R}-1} = 0.0347 & 8\,540713
\end{array}$$

Hence it appears that the dispersive power of water is 0.0347.*

By this method the dispersive powers in the following table have been found. The first column contains the values of $\frac{d\,\text{R}}{\text{R}-1}$, which is the natural measure of the dispersive power; and the second column contains the values of $d\,\text{R}$, or the part of the whole refraction to which the dispersion is equal.

The different dispersive powers comprehended in the Table, vary from 0.022, the dispersive power of *Cryolite*, to 0.400, the estimated dispersive power of the greatest refraction of *Chromate of lead*.

The substances at the head of the Table, between the dispersive powers of 0 0128 and 0.400, present us with results of unexpected magnitude. *Chromate of lead*, *realgar*, and *phosphorus*, included within these limits, might, from their chemical properties, be supposed to possess a great degree of dispersion; but the *oil of cassia*, which exceeds even phosphorus in dispersive power, exerts a most surprising power in separating the extreme rays.

In the two simple inflammable substances, sulphur and phosphorus, and in the metallic salts, a high refractive density is accompanied with a high power of dispersion.

In the *precious stones*, on the contrary, a great refractive power, exceeding that of flint glass, is attended with a dispersive power generally much lower than water.

The dispersive powers of the *resins*, *gums*, *oils*, and *balsams*, greatly exceed that of water, and correspond in some measure with their powers of refraction.

The different kinds of *glass coloured with metals* have a higher dispersive as well as a higher refractive power than flint glass.

The *muriatic*, the *nitric*, and the *nitrous acids*, have dispersive powers considerably above water; while the *sulphuric*, the *phosphoric*, the *citric*, and the *tartaric acids*, which surpass the former in refractive density, possess very inferior powers of dispersion.

Fluor spar and *cryolite*, minerals in which fluoric acid is a principal ingredient, have the lowest dispersive powers of all bodies, and the lowest refractive powers of all solid substances.†

The most singular result, however, in the following Table, relates to the *dispersive powers of doubly refracting substances*. The first experiment which Dr Brewster made upon these crystals, was to determine the dispersive power of Iceland spar, and, from a cause merely accidental, he corrected the colour of the least refraction. The result thus obtained was 0.026, considerably below water, which stands at 0.035 of the scale; and upon comparing it with the place assigned to Iceland crystal by Dr. Wollaston, Dr. Brewster was surprised to find that he placed its dispersive power very considerably above water, and even above diamond. This unexpected difference between the two measures induced him to repeat the experiments, not only with other prisms of the Iceland spar, but also with other standard prisms of flint and crown glass. These new results served only to confirm the accuracy of the first experiment, and to strengthen his suspicion that Dr. Wollaston had committed some mistake. As this reasoning, however, was founded on the assumption which both Dr. Wollaston and Dr. Brewster had made, that the spar had only one dispersive power, he resolved to measure the dispersive power of the extraordinary refraction. This new value having turned out to be greater than that of water, he immediately saw that Dr Wollaston had measured the colour of the greatest refraction, while he had measured the colour of the least; and that this remarkable mineral, which had so long perplexed philosophers by its double refraction, possessed the no less extraordinary and inexplicable property of *two dispersive powers*. In subjecting to examination other crystals that afforded double images, such as carbonate of strontites, carbonate of lead, and chromate of lead, he found that every separate refraction possessed a separate dispersive power. This general law, though not repugnant to any optical phenomena, is still of such a nature, that it could not have been inferred *a priori* from any relation which is known to subsist between the refractive and dispersive powers. No person, indeed, has even conjectured, that a double dispersive should accompany a double refractive power;[*] and if we were to reason in this case from an analogy founded on experiment, an analogy, too, which is by no means remote, we should certainly conclude, contrary to the fact, that the greatest refractive power would be accompanied with the least power of dispersion. In all the minerals in which a metal is the principal ingredient, those which have the greatest refractive density have also the greatest faculty of producing colour; while in all the precious stones a high refractive power is attended with a low power of dispersion.

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* Another observation upon water, with a smaller standard prism of flint glass, makes $d\,\text{R} = 0.0119$, and $\frac{d\,\text{R}}{\text{R}-1} = 0.0352$.

† The *Topaz*, which contains from 17 to 20 parts of fluoric acid, has a dispersive power nearly as low as fluor spar; but, like the other precious stones, it has a great power of refraction.

Table of the Dispersive Powers of various Substances.

Names of the Substances.	Dispersive power, or values of $\frac{d\,R}{R-1}$	Part of the whole refraction to which the dispersion is equal, or values of $d\,R$.
Chromate of lead (greatest refraction) estimated at	0.400	0.770
Chromate of lead (greatest refraction) must exceed	0.296	0.570
Realgar, a different kind, melted	0.267	0.394
Chromate of lead (least refraction)	0.262	0.388
Realgar, melted	0.255	0.374
Oil of cassia	0.139	0.089
Sulphur after fusion	0.130	0.149
Phosphorus	0.128	0.156
Sulphuret of carbon	0.115	0.077
Balsam of Tolu	0.103	0.065
Balsam of Peru	0.093	0.058
Carbonate of lead (greatest refraction)	+0.091	+0.091
Barbadoes aloes	0.085	0.058
Essential oil of bitter almonds	0.079	0.048
Oil of anise seeds	0.077	0.044
Acetate of lead, melted	0.069	0.040
Balsam of styrax	0.067	0.039
Guiacum	0.066	0.041

Names of the Substances.	Dispersive power, or values of $\frac{d\,R}{R-1}$	Part of the whole refraction to which the dispersion is equal, or values of $d\,R$.
Carbonate of lead (least refraction)	0.066	0.056
Oil of cummin	0.065	0.033
Essential oil of tobacco	0.064	0.035
Gum ammoniac	0.063	0.037
Oil of Barbadoes tar	0.062	0.032
Oil of cloves	0.062	0.033
Green coloured glass	0.061	0.037
Sulphate of lead	0.060	0.056
Deep red glass	0.060	0.044
Oil of sassafras	0.060	0.032
Muriate of antimony (Refr. Pr. 1.598)	0,059	0.036
Opal-coloured glass	0.060	0.038
Rosin	0.657	0.032
Oil of sweet fennel seeds	0.055	0.028
Oil of spearmint	0.054	0.026
Orange coloured glass	0.053	0.042
Rock salt	0.053	0.029
Caoutchouc	0.052	0.028
Oil of pimento	0.052	0.026
Flint glass	0.052	0.032
Deep purple glass	0.051	0.031
Oil of angelica	0.051	0.025
Oil of thyme	0.050	0.024
Oil of fenugreek	0.050	0.024

Names of the Substances.	Dispersive power, or values of $\frac{d\,R}{R-1}$	Part of the whole refraction to which the dispersion is equal, or values of $d\,R$.
Oil of wormwood	0.049	0.022
Oil of pennyroyal	0.049	0.024
Oil of caraway seeds	0.049	0.024
Oil of dill seeds	0.049	0.023
Oil of bergamot	0.049	0.023
†Flint glass	0.048	0.029
Chio turpentine	0.048	0.028
Gum thus	0.048	0.028
Oil of lemon	0.048	0.023
Flint glass	0.048	0.028
Oil of juniper	0.047	0.022
Oil of chamomyle	0.046	0.021
Gum juniper	0.046	0.025
Carbonate of strontites (greatest refraction)	0.046	0.032
Oil of brick	0.046	0.021
Nitric acid	0.045	0.019
Oil of lavender	0.045	0.021
Balsam of sulphur	0.045	0.023
Tortoise shell	0.045	0.027
Horn	0.045	0.025
Canada balsam	0.045	0.024
Oil of marjoram	0.045	0.022
Gum olibanum	0.045	0.024
Nitrous acid	0.044	0.018
Cajeput oil	0.044	0.021

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[*] In a Table of refracting powers, published by M. Cavallo in his *Elements of Natural Philosophy*, he has added, from different authors, a numerical estimate of the dispersion, or dissipation, as he calls it, of a very few substances, and for each refraction of the Iceland spar, he has given a separate measure of its *dispersion*. These, however, are not measures of its two dispersive powers, as will be perfectly obvious by inspecting the Table, but merely of the quantity of colour produced by each refraction, which is of course proportioned to the refractions themselves;—in the same manner as two prisms of flint glass, with different angles, have two *dispersions*, though the *dispersive power* of both is the same.

These measures of dispersion, copied by Cavallo, were taken by the late venerable Abbé Rochon, and in a review of Dr. Brewster's *Treatise on Phil. Inst.* written by M. Arago, and published in the *Bulletin de la Société Philomathique*, 1814, p. 38, note, the observation of the Abbé Rochon, that the two images of Iceland spar had different degrees of colour, is said to be an anticipation of Dr. B.'s discovery of double dispersion. As Dr. B. knew that the two dispersions were entirely different from two dispersive powers, he went to the Abbé Rochon in the autumn of 1814, accompanied by his friend Alexander Scott, Esq. and that candid philosopher frankly acknowledged that he had never even computed its dispersive power, and alluded only to the two dispersions. Dr. B. communicated the result of this conversation personally to M. Arago, who expressed his regret that he had made the mistake; but we cannot discover any correction of it in any subsequent volume.

[†] The dispersive power of the different kinds of flint glass tried by Boscovich, varies from 0.0457 to 0.0525. Dr. Robison informs us, that he examined, with great care, a parcel of flint glass, whose dispersive power was 0.038. We suspect that he has committed some mistake in the reduction of his experiments.

Table of the Dispersive Powers of various Substances—continued.

Names of the Substances.	Dispersive power, or values of $\frac{dR}{R-1}$	Part of the whole refraction to which the dispersion is equal, or values of dR
Oil of hyssop	0 044	0.022
Oil of rhodium	0.044	0.022
Pink coloured glass	0.044	0.025
Oil of savine	0.044	0.021
Oil of poppy	0.044	0.020
Zircon (greatest refraction)	0.044	0.045
Muriatic acid	0.043	0 016
Gum copal	0.043	0.024
Nut oil	0 043	0.022
Burgundy pitch	0.043	0.024
Oil of turpentine	0.042	0.020
Oil of rosemary	0.042	0.020
Feldspar	0.042	0.022
Glue	0.041	0.022
Balsam of Capivi	0.041	0.021
Amber	0.041	0.023
Oil of nutmeg	0.041	0.021
Stilbite	0.041	0.021
Oil of peppermint	0.040	0.019
Spinelle ruby	0.040	0.031
Calcareous spar (greatest refraction)	0.040	0.027
Oil of rapeseed	0.040	0.019
Bottle glass	0.040	0.023
Tartrate of potash and soda	0.039	0.020
Gum Elemi	0.039	0.021
Sulphate of iron	0.039	0.019
Diamond	0.038	0.056
Oil of olives	0.038	0.018
Gum mastich	0.038	0.022
White of an egg	0.037	0.013
Oil of rhue	0.037	0.016
Gum myrrh	0.037	0 020
Beryl	0 037	0.022
Obsidian	0 037	0.018
Ether	0.037	0.012
Selenite	0.037	0.020
Alum	0.036	0.017
Castor Oil	0 036	0.018
Sulphate of copper	0.036	0.019
*Crown glass, very green	0 036	0.020
Gum-Arabic	0 036	0.018
Sugar, after being melted and cooled	0.036	0.020
Jelly fish, body of, (*Medusa Æquorea*)	0.035	0.013
Water	0.035	0.012
Aqueous humour of a haddock's eye	0.035	0.012
Vitreous humour of do.	0.035	0.012
Citric acid	0.035	0.019
Rubellite	0 035	0 027
Leucite	0.035	0 018
Epidote	0.035	0.024
Glass of borax	0 034	0.018
Garnet	0 033	0.027
Pyrope	0.033	0.026
Chrysolite	0 033	0.022
Crown glass	0.033	0.018
Oil of ambergrease	0.032	0.012
Oil of wine	0.032	0.012
Phosphoric acid, solid prism, yellow	0.032	0.017
Glass of phosphorus, white	0.03157	0 017
Plate glass	0.032	0 017
Sulphuric acid	0.031	0.014
Tartaric acid	0.030	0 016
Nitre, (least refraction)	0.0304	0.009
Borax	0 030	0.014
Axinite	0.030	0.022
Alcohol	0.029	0 011
Sulphate of barytes	0.029	0.011
Tourmaline	0.028	0.019
Phosphoric acid, fluid	0.0283	0.012
Carbonate of barytes (least refraction)	0.0285	0.015
†Carbonote of strontites, (least refraction)	0.027	0.015
Rock crystal	0.026	0.014
Emerald	0.026	0.015
Borax glass, 1 bor. 2 silex.	0.026	0.014
Calcarenus spar, (least refraction)	0.026	0.016
Blue sapphire	0.026	0.021
Bluish topaz from Cairngorm	0.025	0.016
Chrysoberyl	0.025	0.019
Blue topaz, from Aberdeenshire	0.024	0.016
Sulphate of Strontites	0.024	0.015
Prussic acid	0 0227	0.080
Malic acid	0.0282	0.011
Fluor spar	0.022	0.010
Cryolite	0.022	0.007

Def. A lens or prism is said to be *Achromatic*, if it form an image *free of colour*, or if it refracts all the rays of white light to one focus.

Prop. XI.

A compound lens may be made achromatic, or nearly free of colour, if it consists of two lenses formed of substances of different dispersive powers, the one being convex, and the other concave, and having their focal lengths proportional to their dispersing powers.

Let AD, Fig. 10. be the compound lens, consisting of a convex lens AB of any substance, suppose *crown glass*, whose focus is at f, and a convex lens of *flint glass* CD, whose focus is at F. Let RA, RB, be parallel rays, incident upon the compound lens AD, whose focal length is E r for red rays, and E v for violet rays. Then putting

$$\left.\begin{array}{l} 1+m:1=\text{Ratio of sines for } \textit{red} \text{ rays.} \\ 1+n:1=\text{Ratio of sines for } \textit{violet} \text{ rays.} \end{array}\right\} \text{In the convex or crown glass.}$$

$$\left.\begin{array}{l} 1+p:1=\text{Ratio of sines for } \textit{red} \text{ rays.} \\ 1+q:1=\text{Ratio of sines for } \textit{violet} \text{ rays.} \end{array}\right\} \text{In the concave or flint glass.}$$

Then, if F is the focal length of the convex lens, and f that of the concave lens, for *red* rays, we have

$$\frac{1}{m}:\frac{1}{n}=\mathrm{F}:\frac{m\,\mathrm{F}}{n} \text{ the focal length of the convex lens for } \textit{violet} \text{ rays.}$$

$$\frac{1}{p}:\frac{1}{q}=f:\frac{pf}{q} \text{ the focal length of the concave lens for } \textit{violet} \text{ rays.}$$

Now, since f is the focus of AB for red rays, and F that of CD for the same rays, the focal length of the compound lens for these rays will be the conjugate focal length of CD for red rays converging to f; that is, $f\mathrm{F} : \mathrm{FE} = \mathrm{E}f : \mathrm{E}\,r$, or $f - \mathrm{F} : \mathrm{F} = f : \mathrm{E}\,r$, and for violet rays it will be $\frac{pf}{r} - \frac{m\,\mathrm{F}}{n} : \frac{m\,\mathrm{F}}{n} = \frac{pf}{r} : \mathrm{E}\,v$. Hence $\mathrm{E}\,r = \frac{\mathrm{F}f}{f-\mathrm{F}}$, and $\mathrm{E}\,v = \frac{mp\,\mathrm{F}f}{npf - mr\mathrm{F}}$. But as

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[*] The dispersive power of the different kinds of common glass (strass,) tried by Boscovich, varies from 0.0330 to 0.0346. Dr. Robison found the dispersive power of some crown glass made at Leith, so low as 0.027.

[†] The dispersive power of the greatest refracted image of the Carbonate of Barytes, when it is bright, is considerably greater than that of the other. See *Edinburgh Transactions*.

the *red* and *violet* rays are by the hypothesis united at the same point of the axis, the focal lengths of the compound lens for both must be equal; that is

$$\frac{Ff}{f-F}=\frac{mpFf}{npf-mrF},$$

and dividing by Ff and reducing, we obtain $npf-mrF=mpf-mpF$; consequently $p(n-m)f=m(r-p)F$, and $F:f=p(n-m):m(r-p)=\frac{n-m}{m}:\frac{r-p}{p}$. But $\frac{n-m}{m}$ and $\frac{r-p}{p}$ are measures of of the dispersion in relation to the refraction, or measure of the dispersive power. Hence it follows, that the extreme red and extreme violet rays are united in one focus, when the focal lengths of the lenses are proportional to the dispersive powers.

This proposition is, however, true only upon the supposition, that the extent of each coloured space in the one medium, has the same relation to the extent of each coloured space in the other medium, as the lengths of their respective spectra; for, if this is not the case, the intermediate colours will not meet in the same focus, even though the extreme rays are united.

Scholium.

The determination of the focal lengths of lenses for rendering telescopes achromotic is a very simple operation; but as it is necessary at the same time to correct the spherical aberration, we must give such curvatures to the surfaces as will produce this effect, and preserve, at the same time, the relation between the focal lengths, which is requisite for correcting the aberration of refrangibility.

Def. The coloured spaces in different spectra are said to be *Irrational*, if they have not the same *ratio* to one another as the total lengths of the spectrum; that is, if the lengths of two spectra, for example, be as 2 to 1, and the length of the green spaces in each in a different ratio, either greater or less, the coloured spaces are said to be irrational, crown glass being generally considered as the standard.

Prop. XII.

Different bodies give different spectra, in which the coloured spaces have not the same ratio to one another as the length of the spectra.

If we combine either two prisms or two lenses of crown and flint glass, so as to correct the *aberration of colour* as completely as possible, it will be found that there remains what has been called a *secondary spectrum*, which consists of two colours, a purple or claret coloured space, and a light green space. By increasing the refracting angles of the prisms, this secondary spectrum will be rendered more perceptible; or it may be increased enormously by using prisms of *oil of cassia* and *sulphuric acid*, which give spectra in which the coloured spaces are more different from one another than those in any other bodies.

In order to explain the phenomena of uncorrected colour, let RRO, Fig 11. be a ray transmitted through a hole in the window-shutter SS, and incident upon a prism P, which refracts the light in the direction PM, and forms on the wall OA the prismatic spectrum AB; PM being the mean ray, PB the extreme red, and PA the extreme violet ray. The spectrum AB, which it forms, will be composed of four colours, *red*, *green*, *blue*, and *violet;* and if the prism is made of crown glass, the mean ray PMN, which divides the spectrum, will be the boundary of the blue and green spaces. If a prism of flint glass, with a less refracting angle, is placed so as to form a spectrum CD of the same size with AB, the boundary $m\,n$ of the green and blue spaces will no longer be the mean ray of the spectrum, but will be considerably nearer the red extremity D. Hence the least refrangible rays will be more *contracted*, and the most refrangible rays more *expanded*, than in the spectrum AB. If a third spectrum EF, of the same length with the other two, is formed by a prism of rock crystal, the mean ray $\mu\nu$ will be nearer the violet extremity of the spectrum, and the least refrangible rays will be more expanded, and the most refrangible ones more contracted, than in the spectrum formed by the crown glass.

If a spectrum formed by flint glass had its coloured spaces exactly of the same dimensions with those of an equal spectrum formed by crown glass, any object, such as the sun, or a window bar lying parallel to the common section of the refracting planes, should appear perfectly colourless when seen through the combined prisms But if the coloured spaces in the two spectra are not proportional, as is represented at AB, and CD, Fig. 11. then the sun, or the window bar, cannot be altogether free from colour; for though the extreme red and violet rays of both the spectra are united, yet the intermediate colours are not rendered coincident In the spectrum AB, formed by the crown glass, the first green ray MN, which is here the mean ray, is obviously more refracted than the first green ray $m\,n$, in the spectrum CD formed by the flint glass, and therefore the flint glass will not be able to refract the green ray, so as to unite it with the red and violet. Hence the green ray will, as it were, be left behind, while the red and violet rays are rendered coincident. Thus, in Fig. 11. if a prism p of flint glass is placed behind a crown glass prism P, so as exactly to correct its dispersion, the spectrum AB will be reduced to a secondary spectrum $a\,b$, the upper half of which is *green*, which is left behind, and the lower half is of a *claret* colour, formed by the union of the red and violet rays. If the bar of a window had been examined through the combined prisms P, p, the upper side of it would have been tinged with green, and the lower side of it with a claret-coloured fringe.

By comparing, in a similar manner, the spectrum EF, formed by rock crystal with the spectrum AB, formed by crown glass, it will be found, that the rock crystal having a greater action than the crown glass upon the green ray, will carry it beyond the place of the united red and violet, and will form a secondary spectrum $e\,f$, the lower half of which is *green*, and the upper half of a *claret* colour, arising from the union of the red and violet light. If the bar of a window were viewed through the combined prisms of crown glass and rock crystal, it would be tinged with green on its lower side, and with a claret-coloured fringe on its upper side.

When a horizontal window bar, therefore, is seen through any two prisms which correct each other's dispersion, without uniting all the colours, the green fringe will always be on the same side of the bar with the vertex of the prism which has the least action upon the green light, or which *contracts* the red and green rays, and *expands* the blue and violet ones; that is, if the vertex of the flint glass prism is pointing downwards, the uncorrected green fringe will be on the lower side of the bar. By observing, therefore, the position of the green fringe, we can immediately ascertain which of the two prisms has the greatest action upon the green light.

These theoretical deductions from the assumed inequality of the coloured spaces, are completely established by observation.*

The following Table contains the result of a numerous series of observations made by Dr. Brewster on the secondary spectra of different bodies, the substances being arranged inversely according to their action upon green light. The bodies at the top of the Table form spectra, in which the red and green spaces are most contracted, and the blue and violet ones most expanded. The relative position of some of the substances, particularly the essential oils, is quite empirical; but, by a reference to the original experiments, it will be seen whether or not the relative action of any two bodies has been determined.†

Table of Transparent Bodies, arranged inversely according to their Action upon Green Light.

1 OIL OF CASSIA.
Sulphur.
Sulphuret of Carbon.
Balsam of Tolu.
5 Carbonate of lead.
Essential oil of bitter almonds.
Oil of anise seeds.
Oil of cummin.
Oil of sasafras.
10 Oil of amber.
Acetate of lead melted.
Opal-coloured glass.
Orange-coloured glass.
Red-coloured glass.
15 Oil of sweet fennel seeds.
Oil of cloves.
Muriate of antimony.
Oil of lavender.
Canada balsam.
20 Oil of Turpentine.
Oil of sage.
Oil of pennyroyal.
Oil of poppy.
Oil of hyssop.
25 Oil of spearmint.
Amber.
Oil of lemon.
Oil of Caraway-seeds.
Oil of nutmegs
30 Oil of thyme.
Oil of peppermint.
Oil of bergamot.
Oil of marjoram.
Oil of wormwood.
35 Oil of dill seeds.
Oil of chamomyle.
Castor-oil.
Gum copal.
Rosin.
40 Diamond.
Nitrate of potash.
Oil of beech-nut.
Oil of rhue.
Oil of Savine.
45 Nut-oil.
Balsam of capivi.
Oil of fenugreek.
Oil of rosemary.
Oil of rhodium.
50 FLINT GLASS.
Zircon
Oil of olives.
Oil of rape seed.
Oil of spermaceti.
55 Oil of juniper.
Oil of ambergris.
Calcareous spar.
Rock-salt.
Gum juniper.
60 Tartrate of potash and soda.
Oil of almonds.
CROWN GLASS.
Gum-Arabic.
Alchohol.
65 Ether.
Borax, glass of.
Borax.
Tourmaline.
Leucite.
70 Selenite.
Beryl.
Topaz, blue.
Fluor-spar.
Citric Acid.
75 Malic Acid.
Acetic acid.
Nitrous acid.
Muriatic acid.
Prussic acid.
80 Nitric acid.
Rock crystal.
White of an egg.
Ice.
WATER.
85 Super-sulphuretted hydrogen.
Phosphorus acid.
Sulphurous acid.
Phosphoric acid.
89 SULPHURIC ACID.

PROP. XIII.

Two prisms may be made to unite all the coloured rays, and two lenses to converge them all to one point, though they are made of the same kind of glass.

The truth contained in this proposition was first determined from experiment by Dr. Brewster, who also deduced it mathematically from the constant ratio of the sines. The position of the prisms and lenses that produce this effect is shown in Figs. 12, 13. The prism B, which has a smaller refracting angle than the prism A, has the line which bisects that angle inclined to the incident ray, in consequence of which its dispersion is increased in a greater ratio than its refraction, so as to correct the dispersion of A. without correcting its refraction. The ray R′D will therefore emerge colourless, and will meet the axis CD in D. The pencil, after refraction through the first prism B, should fall upon A in such a manner that the mean ray may enter the prism A, and emerge from it at equal angles; for it has already been shown in Prop. VII. p. 634, that in this position its refraction and dispersion will be a minimum. For farther information on this subject, see Dr. Brewster's *Treatise on New Philosophical Instruments*, p. 400; and the *Edinburgh Philosophical Journal*, vol. vi. p. 334. See also a paper by Professor Amici, in the *Memorie della Societe Italiana*, tom. xix. or an abstract of it in the *Bibliotheque Universelle*, Nov. 1821, p. 174.

PROP. XIV.

When the dispersion of one prism is corrected by another prism with a different angle, but made of the same kind of glass, there is an irrationality in the coloured spaces, which prevents the correction of colour from being complete.

This fact, which was discovered by Dr. Brewster, may be deduced mathematically from the constant ratio of the sines of incidence and refraction. To the uncorrected colour which thus remains, he has given the name of the *Tertiary Spectrum*, in order to distinguish it from the *Secondary Spectrum* above described. The *Secondary Spectrum* being produced by a specific quality in the refracting media, while the *Tertiary Spectrum* depends wholly upon the angles by which light is refracted at the two surfaces of the prism. As the magnitude of the latter may be determined accurately by calculation, Dr. Brewster has proposed to make use of it as a measure of the secondary spectrum.

PROP. XV.

To exhibit the *Tertiary Spectrum* by the opposite actions of the two surfaces of the same prism.

In examining the phenomena of the tertiary spectrum, Dr. Brewster was led to observe a very paradoxical method of exhibiting it by a single prism. He took a prism of oil of cassia, with a very large refracting angle; and having viewed through it the broadest horizontal bar of a window, so that its edges were quite free of colours, he inclined the prism in such a manner that the bar exhibited at its edges the prismatic colours, as shown in Fig. 14. The edges *b* M, and *e* N of the bar, had spectra *b a* M, *e f* N, consisting of the usual *red* and *yellow* rays; and the edges *e* M, *b* N, had spectra *e d* M, *b c* N, consisting of the usual *blue* and *violet* rays. These spectra increased from *b* and *e*, towards M and N, and at the points or nodes *b*, *e*, where the spectra would have vanished had each face of the prism received the rays symmetrically, the *tertiary spectrum* was distinctly seen in the form of a green and claret-coloured fringe.

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* *Treatise on New Philosophical Instruments*, p. 354.

† See *Edinburgh Transactions*, vol. viii. p. 23.

Prop. XVI.

To describe the optical phenomena of the spectrum, particularly those discovered by M. Fraunhofer.

In the years 1814 and 1815, M. Fraunhofer of Benedictbaiern, near Munich, who has been long celebrated for the excellence of his achromatic telescopes, published an account of a series of experiments on the prismatic spectra formed by different bodies, which he had undertaken for the purpose of improving the achromatic telescope.

Having succeeded by a very ingenious contrivance in obtaining homogeneous coloured images from the different rays of the spectrum, as shown at Fig. 15. where PQ is the spectrum from an aperture, and O, N, M, L, K, I, the homogeneous images, N always corresponding with the bright reddish yellow stripe AR, or D, of Fig. 16. M. Fraunhofer proceeded to measure the distances ON, NM, &c. in the spectra produced by various solid and fluid bodies, and he obtained the results in the following Table.

Refracting Media.	Temperat. Reaumur.	Specific Gravity.	Angle of the Prism.	Angle of Deviation	See Plate CCCCXXXIII. Fig. 15.				
					ON	NM	NL	NK	NI
	°		° ′ ″	° ′ ″	′ ″	′ ″	′ ″	′ ″	′ ″
Crown glass, No. 9.	3	2.535	39 20 35	22 38 20	6 1	5 46	11 22	16 56	22 16
Flint glass, No. 13.	5½	3.723	26 24 30	17 27 9	7 17	7 15	14 18	21 31	28 46
Water	8	1.000	58 5 40	22 36 41	6 35	6 19	12 9	17 45	23 18
Water	9¼	1 000	58 5 40	22 36 43	6 30	6 12	12 5	17 43	23 10
Sulphuric acid	9½	1.841	58 5 40	29 27 47	7 50	7 15	14 3	20 30	26 45
Alcohol	9	0.809	58 5 40	25 8 32	6 35	6 17	12 55	18 45	
Sulphuric Ether	9		58 5 40	24 38 39	6 20	6 27	12 55	19 10	
Oil of turpentine	7	0.885	58 5 40	33 22 8	11 00	11 35	22 45	34 20	
Sol. of potash in water	8½	1.416	58 5 40	27 45 54	8 32	7 58	15 35	23 6	30 24
Acetate of lead	8½		58 5 40	24 34 49	7 54	7 31	14 47	21 40	28 22
Oil of turpertine	8½	0.885	58 5 40	33 20 8	11 5	11 32	22 45	33 56	44 50

From these results he computed the following indices of refraction for flint-glass, crown-glass, and water; ON representing the red ray, and I *n* the violet one.

Refracting Media.	O *n*	N *n*	M *n*	L *n*	K *n*	I *n*
Flint glass, No. 13.	1.63074	1.63505	1.63933	1.64349	1.64775	1.65203
Crown glass, No. 9.	1.52736	1.52959	1.53173	1.53380	1.53586	1.53783
Water.	1.33209	1.33359	1.33501	1.33635	1.33763	1.33888

From these data he obtains the ratio of the action of any two of these bodies on the different colours of the spectra thus:

Refracting Media.	$\frac{Nn'-On'}{Nn-On}$	$\frac{Mn'-Nn'}{Mn-Nn}$	$\frac{Ln'-Mn'}{Ln-Mn}$	$\frac{Kn'-Ln'}{Kn-Ln}$	$\frac{In'-Kn'}{In-Kn}$
Flint glass, No. 139. Crown glass, No. 9.	1.93	2.00	2.01	2.07	2.17
Flint glass, No. 139. Water.	2.87	3.01	3.10	3.33	3.42
Crown glass, No. 93. Water.	1 49	1.51	1.55	1.61	1.58

By using prisms perfectly free of veins, and carefully excluding all extraneous light, and even stopping those rays which formed the coloured spaces which he was not examining, he discovered that the spectrum was covered with a great number of black lines, parallel to one another, and perpendicular to the length of the spectrum. In order to see them distinctly, it is necessary that the light enter and emerge from the prism at equal angles. By examining the spectra formed by various solid and fluid bodies, he not only discovered that they all possessed the same lines, but that these lines had fixed positions, the distances between which in different spectra afforded precise measures of the action of the prism on the rays which formed the corresponding coloured spaces.

The lines discovered by M. Fraunhofer, are represented in Plate CCCCXXXIII. Fig. 16. Below which we have added, in Fig. 1. the spectrum according to Newton. with his division of the coloured spaces, in order that the relation between the lines in the one, and the colours in the other, may be more easily perceived.

Beginning at the red end of the spectrum, M. Fraunhofer observed the following lines.

At A there is one dark line	1
At *a* there are seven or eight very close together	8
At B there is one quite black, and a fainter one	2
Between B and C, the one at C being very perceptible	9
Between C and D	30
At D two nearly of the same size	2
Between D and E	84
Between E and *b*	24
At *b* three very strong lines	3
Between B and F, the one at F very strong	52
Between F and G	185
Between G and H	190
In all about	590

At H there are two very remarkable places, perfectly close, and darker than the rest, and consisting of a number of dark *violet* lines.

M. Fraunhofer examined the spectra produced by the two polarised pencils of a prism of Iceland spar, and he found them to have the same lines as the spectra produced by common light.

By means of a theodolite furnished with a telescope, M. Fraunhofer measured the distance of the most prominent lines, viz. BC, CD, DE, EF, FG, and GH, in various bodies, as in the following table.

Refracting Media.	Tempera. Reaumur.	Specific Gravity.	Angle of the Prism.	Angle of Deviation.	BC	CD	DE	EF	FG	GH
	°		° ′ ″	° ′ ″	′ ″	′ ″	′ ″	′ ″	° ′ ″	° ′ ″
Flint glass, No. 13.	15	3.723	26 24 30	17 27 8	3 16	9 4.2	11 50	10 33.9	20 23 9	18 18
Crown glass, No. 9.	14	2.535	39 20 35	22 38 19	2 44.5	7 23.5	9 14	8 14	15 10	13 18
Water	15	1.000	58 5 40	22 36 40	3 24	8 10	9 58	8 38	15 16	12 41.9
Water	15	1.000	58 5 40	23 36 40	3 12.4	8 10.6	9 57.5	8 30.5	15 15.6	12 46.2
Sol. of potash in water	9	1.416	58 5 40	27 45 56	4 2	10 26	12 54	11 12	20 36	17 24
Oil of Turpentine	8½	0.885	58 5 40	33 20 12	4 56	13 52	18 46.1	16 14	31 8	27 28
Flint glass, No. 3.		3.512	27 41 35	17 85 16.6	3 8	8 22	10 46	9 50	19 10	17 10
Flint glass, No. 30.		3 695	21 42 15	14 3 9	2 35.6	6 56.8	9 12.6	8 19	16 15.6	14 32 2
Crown glass, No. 13.		535	43 27 36	25 26 35 4	3 5	8 14.4	10 28 2	9 10	17 14.8	14 48.4
Crown glass.		2 756	43 56 40	26 39 13	3 32.8	9 37.6	12 29.8	11 1.6	20 53.6	18 17.4
Flint glass, No. 23.		3.724	60 15 42	49 55 13.2	11 12.6	31 14 8	41 21.4	38 14 8	1 14 45.2	18 3 6
Flint glass, No. 23.		3.724	45 23 14	32 45 12.2	6 26	17 47.8	23 31.8	21 23.8	41 33.4	37 28.8

From these data he computed, by the formulæ which we have given in Prop. IX. p. 634, the *Indices of refraction* for the rays at the points B, C, D, E, F, G, and H, which he designates by B n, C n, &c. the results of which are given in the following Table.

Refracting Media.	B n	C n	D n	E n	F n	G n	H n
Flint Glass, No. 13.	1.627749	1.629681	1.635036	1.642024	1.648260	1.660285	1.671062
Crown glass, No. 9....	1.525832	1.526849	1.529587	1.533005	1.536052	1.541657	1.546566
Water.........................	1.330935	1.331712	1.333577	1.335851	1.337818	1.341293	1.344177
Water..............................	1.330977	1 331709	1.333577	1.335849	1.337768	1 341261	1.344162
Solution of potash in water.............	1.399629	1.400515	1.402805	1.405632	1.408082	1.412579	1.416368
Oil of turpentine..................................	1.470496	1 471530	1.474434	1.478353	1.481736	1.488198	1.493874
Flint glass, No. 3............................ .	1.602042	1.603800	1.608494	1.614532	1.620042	1.630772	1.640373
Flint glass, No 30..............................	1 623570	1 625477	1.630585	1.637356	1.643466	1.655406	1.666072
Crown glass, No. 30............................	1.524312	1.525299	1.527982	1.531372	1.534337	1 539908	1.544684
Crown glass..	1.554774	1.555933	1.559075	1.563150	1.566741	1.573535	1.579470
Flint Glass, No. 23. Prism of 60°...	1.626596	1.628469	1.633667	1.640495	1.646756	1.658848	1.669686
Flint glass, No. 23. Prism of 45°....	1.626564	1.628451	1.633666	1.640544	1.646780	1 658849	1.669680

He then compares the index of refraction for the mean ray in each of the above divisions, as obtained for two different substances, such as crown and flint glass, and in that way he obtains the ratio of their action upon rays at different parts of the spectrum. These results are given in the following Table.

Refracting Media.	$\frac{Cn'-Bn'}{Cn-Bn}$	$\frac{Dn'-Cn'}{Dn-Cn}$	$\frac{En'-Dn'}{En-Dn}$	$\frac{Fn'-En'}{Fn-En}$	$\frac{Gn'-Fn'}{Gn-Fn}$	$\frac{Hn'-Gn'}{Hn-Gn}$
Flint glass, N° 13 and water.......................	2.562	2.871	3.073	3 193	3.460	3.726
Flint glass, N° 13 and Crown glass, N° 9.	1.900	1.956	2.044	2.047	2.145	2.195
Crown glass N° 9. and Water.....................	1.349	1.468	1 503	1.560	1.613	1.697
Oil of Turpentine and Water.............	1.371	1 557	1.723	1.732	1.860	1.963
Flint glass, N° 13. and Oil of Turpentine.	1.868	1.844	1.783	1.843	1.861	1.899
Flint glass, N° 13. and Kali.....	2 181	2.338	2.472	2.545	2.674	2.844
Kali and Water.......................................	1.175	1 228	1.243	1.254	1.294	1 310
Oil of Turpentine and Kali..........................	1.167	1.268	1.386	1.381	1.437	1.498
Flint glass, N° 3. and Crown glass, N° 9..	1.729	1.714	1.767	1.808	1.914	1.956
Crown glass. N° 13. and Water.................	1.309	1.436	1.492	1.518	1.604	1.651
Crown glass and Water............	1.537	1.682	1.794	1.839	1.956	2.052
Crown glass, N° 2. and Crown glass, N° 13	1 174	1.171	1.202	1.211	1.220	1.243
Flint glass, N° 13. and Crown glass..	1.667	1.704	1.715	1.737	1.770	1.816
Flint glass, N° 3. and Crown glass	1 517	1.494	1.482	1.534	1.579	1.618
Flint glass, N° 30. and Crown glass. N° 13.	1.932	1.904	1.997	2 061	2.143	2.233
Flint glass, N° 23. and Crown glass, N° 13	1.904	1.940	2 022	2.107	2.168	2.268

Having thus ascertained the action of these bodies upon the different points of the spectrum. M. Fraunhofer proceeded to measure the illuminating power of the different rays, and by means of a photometer he obtained the results which are expressed by the ordinates of the curve in Fig. 17. where any ordinate, such as D d, represents the illuminating power of the point D of the spectrum.

In order to find this curve, M. Fraunhofer made many experiments, of which the following are the average results. Calling the maximum illuminating power, or that between D and E, 1.000, the illuminating power of other principal points will be as follows:

Points in the Spectrum.	Intensity of the light at these points.
B	0.032
C	0.094
D	0.64

Points in the Spectrum	Intensity of the light at these points
Between D and E	1.00
E	0.48
F	0.17
G	0.031
H	0.0056

Or if we call the intensity of the light in the whole space DE 1.00, the intensity of the light in the other spaces will be as follows:

Intensity of light in the space BC=0.021
Intensity of light in the space CD=0.299
Intensity of light in the space DE=1.000
Intensity of light in the space EF=0.328
Intensity of light in the space FG=0.185
Intensity of light in the space GH=0·035

Prop. XVI.

To describe the physical properties of the spectrum.

Having already given a full account, in the history of optics, of the discoveries of Dr. Herschel, Mr. Ritter, Dr. Wollaston, M. Berard, and Dr. Morichini, respecting the heating power of the spectrum, its deoxidating property, and the faculty possessed by the violet rays of magnetising steel, it is unnecessary to resume the subject.

Before we conclude this chapter on chromatics, it may be necessary to consider the explanation of the dispersion of light which is given by the theories of emission and undulation. In the Newtonian theory of emission, refracting media are supposed to have an elective attraction, acting more powerfully on the violet rays, in proportion to their mass, than upon the red rays. The theory of undulations, however, affords a less satisfactory explanation. "It is not indeed, very easy," says Dr. Young, "to give a demonstrative theory of the dispersion of coloured light upon the supposition of undulatory motion, but we may derive a very satisfactory illustration from the well known effects of waves of different breadths. The simple calculation of the velocity of waves, propagated in a liquid perfectly elastic, or incompressible, and free from friction, assigns to them all precisely the same velocity, whatever their breadth may be: the incompressibility of the fluids actually introduces, however, a necessity for a correction, according to the breadth of the wave; and it is very easy to observe in a river or a pond of considerable depth, that the wider waves proceed much more rapidly than the narrower. We may therefore consider the pure ethereal medium as analogous to an infinitely elastic fluid, in which undulations of all kinds move with equal velocity; and material transparent substances, on the contrary, as resembling those fluids, in which we see the large waves advance beyond the smaller: and by supposing the red light to consist of larger or wider undulations, and the violet of smaller, we may sufficiently elucidate the greater refrangibility of the violet than of the red."*

CHAP. IV.

ON THE INFLEXION OF LIGHT, AND THE LAW OF INTERFERENCE.

The term Inflexion, which is synonimous with Diffraction, has been applied to designate those phenomena which are exhibited by light when it passes near the edges of bodies.

About the same time that Dr. Hooke made the experiments on the inflexion of light, of which we have given some account in the history of Optics, Father Grimaldi was busily occupied with the same subject. Having admitted a ray of light through a very small hole, AB, Fig. 18. into a dark chamber, he observed that the light was diffused in the form of a cone, having CD for its base. When any opaque body EF was placed in this divergent light, at some distance from the hole, the boundaries of its shadows were not confined within GH, a space bounded by the lines AEH and BFG, nor within the penumbra IL, formed by the lines BEL and AFI, but extended to MN, so that the shadow occupied a considerably greater space than if it had been formed by rays passing in straight lines by the extremities of the object.

Without the shadow, between C and M, and N and D, Grimaldi observed three fringes of coloured light, shown in Fig. 19. where MNO is the broadest and most luminous next to the shadow X. In the space M there was no colour, but NN was *blue*, and OO *red*. The second fringe QPR was narrower than the first, the space P had no colour, but QQ was a *faint blue*, and RR a *faint red*. The third fringe STV was the same as the other two, but narrower than either, and having its colour more faint.

When the body EF was of an angular form, the fringes were bent into a curve round the salient angles, as at D, Fig. 20. and when the angles were re-entrant, as at C, the coloured fringes crossed without obliterating one another, the tints being either mixed or rendered more intense.

Besides the fringes above described, Grimaldi discovered others within the shadows of bodies. These fringes were most distinctly seen when the light was intense, the body long, and the shadow received at a distance from the body. The number of streaks increased with the breadth of the plate. There were at least *two* of them, and *four* if a thicker plate was used, but they were broader when few in number, and narrower when more numerous, and they were always most distinct when the paper was held obliquely.

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* *Lectures on Natural Philosophy*, vol. i. p. 463.

The internal fringes were bent round the angles of the shadow as shown in Fig. 21. where ADBC is the shadow, and *a*, *b*, *c*, *d*, the internal fringes. At the angle D short lucid streaks were visible but in the form of a plume, and returning again to D.

One of the most curious phenomena observed by Grimaldi related to the interference of two cones of light issuing from two contiguous apertures. This phenomenon he announces in the following manner: "*A body actually illuminated may become more dark by adding a new light to that which it already receives.*" In order to prove this paradoxical proposition, he admits two cones of light into a dark chamber through two small apertures placed near to each other, so that the cones do not begin to penetrate one another till at a certain distance. By receiving the light upon a piece of white paper held at a greater distance from them, the two circular bases of the luminous cones will overlap one another, as shown in Fig. 22. where ABCD, AFCE, are the two circles having a common segment ADCF. When one of the apertures is closed, only one cone of light will be visible, for example, the one ABCD; and it will be seen that the middle part of the circle is more luminous than the circumference, and that the light decreases as the distance from the centre increases The very same is the case when the other cone is examined alone.

But when the two apertures are open at the same time, the common segment ADCF is more luminous than the circumference of the two bases; but *the two arches* ADC *and* AFC *have a remarkable degree of obscurity*, though they receive more light than the rest of the circumference of which they form a part. If the paper which receives the rays is brought nearer to the window, so that the segment ADCF may diminish, a position will be found in which the arches ADC, AFC, will become red; but if the paper is withdrawn from the window, so that the segment ADFC may increase, the arches ADC and AFC will become more and more obscure.

The experiments of Grimaldi on the inflexion of light were repeated and extended by Sir Isaac Newton. Having made in a piece of lead a small hole about the 42dth part of an inch in diameter, and admitted through it the sun's light, he found that the shadows of all substances were much broader than they ought to be; and he measured the breadth of the shadow of a human hair, the 280th part of an inch in diameter at different distances.

Distance of the hair from the hole.	Distance of the paper receiving the shadow from the hair.	Breadth of the shadow.
12 feet	4 inches	0.01666 inches
12 feet	24 inches	0.03572 inches
12 feet	120 inches	0.125 inches

Newton obtained also the following measures, when the hair was 12 feet distant from the hole, at the different distances of *half a foot* and *nine feet*.

At the Distance of	Half a foot.	9 feet.
Breadth of the shadow	$\frac{1}{54}$	$\frac{1}{9}$
Breadth between the middles of the brightest light of the innermost fringes on either side of the shadow	$\frac{1}{38}$ or $\frac{1}{39}$	$\frac{7}{50}$
Breadth between the middles of the brightest light of the middlemost fringes on either side of the shadow	$\frac{1}{23\frac{1}{2}}$	$\frac{4}{17}$
Breadth between the middles of the brightest light of the outmost fringes on either side of the shadow	$\frac{1}{18}$ or $\frac{1}{18\frac{1}{2}}$	$\frac{3}{10}$
Distance between the middles of the brightest light of the first and second fringes	$\frac{1}{120}$	$\frac{1}{21}$
Distance between the middles of the brightest light of the second and third fringes	$\frac{1}{170}$	$\frac{1}{31}$
Breadth of the luminous part (*green white*, *yellow*, and *red*) of the first fringe	$\frac{1}{170}$	$\frac{1}{32}$
Breadth of the darker space between the first and second fringes	$\frac{1}{240}$	$\frac{1}{45}$
Breadth of the luminous part of the second fringe	$\frac{1}{290}$	$\frac{1}{55}$
Breadth of the darker space between the second and third fringes	$\frac{1}{340}$	$\frac{1}{63}$

When the hair was surrounded with water, the very same phenomena were produced. In order to explain these phenomena, Sir Isaac supposes that X, Fig. 23. represents a section of the hair; ADG, BEH, CFI, three rays passing by one side of it; D, E, F, and N, O, P, the places where the rays are bent in passing by the hair; G, H, I, and Q, R, S, the places where the rays fall upon the paper GQ; IS the breadth of the shadow of the hair on the paper; and TI, VS. two rays passing to the points I and S without bending when the hair is taken away. He then conceives, that all the light between TI and VS is bent in passing by the hair, and turned aside from the shadow IS; that the hair acts upon the passing rays at a "good distance;" that the action is strongest on those which pass at least distance, and grows weaker and weaker with the distance, as shown in Fig. 23; and that from these causes "the shadow of the hair is much broader in proportion to the distance of the paper from the hair when the paper is nearer the hair, than when it is at a great distance from it."

When examining the light without the shadows of metals, stones, glass, wood, horn, ice, &c. Newton found that the shadows were bordered with three parallel fringes of coloured light, diminishing in breadth with their distance from the shadow. By receiving the shadow obliquely on a smooth paper, the first or innermost colour was *violet*, or *deep blue* next the shadow, then *light blue*, *green* and *yellow* in the middle, and *red*. The second and third were both *blue* within, and *yellow* and *red* without; but the colours were very faint. Hence the orders of colours were,

First fringe, violet, indigo, pale blue, green, yellow, red.
Second fringe, blue, yellow, red.
Third fringe, pale blue, pale yellow, red.

Upon comparing the breadths of the fringes and their intervals at different distances, Newton found them to be nearly in the same proportion, the breadth of the fringes being as the numbers 1, $\sqrt{\frac{1}{3}}$, $\sqrt{\frac{1}{5}}$, &c. and their intervals to be in the same progression; that is, their fringes and their intervals together to be as the continual progression of the numbers 1, $\sqrt{\frac{1}{2}}$, $\sqrt{\frac{1}{3}}$, $\sqrt{\frac{1}{4}}$, $\sqrt{\frac{1}{5}}$.

The next experiments made by our author, related to the fringes formed by the light which passed by the edge of a knife, and to those formed when the light passed between two knife edges parallel to one another.

From these experiments Newton concluded, that the light of the *first fringe* passed by the edge of the knife at a distance greater than the 800th of an inch;—that the light of the *second fringe* passed by the edge of the knife at a greater distance than the light of the *first fringe*, and that of the *third* at a greater distance than that of the *second*.

He then had the edges of two knives ground straight, and fixed their points into a board, so that their edges contained an angle of 1° 47′ 26″. The knives being thus fixed, he placed them in a beam of the sun's light, admitted through a hole the 42d of an inch wide, at the distance of 10 or 15 feet from the hole; and he let the light which passed between their edges fall very obliquely on a smooth white ruler, at the distance of half an inch, or an inch, from the knives; and there he saw the fringes made by the two edges of the knives run along the edges of the shadows of the knives, in lines parallel to those edges, without growing sensibly broader, till they met in angles equal to the angle contained by the edges of the knives; and where they met and joined, they ended, without crossing one another. But if the ruler was held at a much greater distance from the knives, the fringes, where they were farther from the place of their meeting, were a little narrower, and they became somewhat broader as they approached nearer to one another, and after they met they crossed one another, and then became much broader than before.

Hence he concluded that the distances at which the light composing the fringes passed by the knives were not increased or altered by the approach of the knives; and that the knife which was nearest to any ray determined which way the ray should be bent, but that the other knife increased the bending.

When the rays fell very obliquely upon the ruler, at the distance of one third of an inch from the knives, the dark line between the first and second fringe of the shadow of one knife, and the dark line between the first and the second fringe of the shadow of the other knife, met one another, at the distance of one-fifth of an inch from the end of the light which passed between the knives, where their edges met; so that the distance of the edges of the knives, at the meeting of these dark lines, was the 160th of an inch; and one half of that light passed by the edge of one knife, at a distance not greater than the 320th part of an inch, and, falling upon the paper, formed the fringes of the shadow of that knife; while the other half passed by the edge of the other knife, at a distance not greater than the 320th part of an inch, and, falling upon the paper, formed the fringes of the shadow of the other knife. But when the paper was held at a distance from the knives greater than one-third of an inch, the dark lines above mentioned met at a greater distance than one-fifth of an inch from the end of the light which passed between the knives, at the meeting of their edges; so that the light which fell upon the paper where those dark lines met passed between the knives, where their edges were farther distant than the 160th of an inch. For at another time, when the two knives were eight feet five inches from the little hole in the window, the light which fell upon the paper where the above mentioned dark lines met passed between the knives, where the distance between their edges was, as in the following table, at the distances from the paper noted.

Distances of the paper from the knives in inches.	Distances between the edges of the knives in thousandth parts of an inch.
$1\frac{1}{2}$	0.012
$3\frac{1}{3}$	0.020
$8\frac{3}{5}$	0.034
32	0.057
96	0.081
131	0.087

From these observations he concluded *that the light which forms the fringes upon the paper is not the same light at all distances of the paper from the knives*;* but that when the paper is held near the knives, the fringes are made by light which passes by the edges of the knives at a less distance, and is more bent than when the paper is held at a greater distance from the knives.

When the fringes of the shadows of the knives fell perpendicularly upon the paper, at a great distance from the knives, they were in the form of hyperbolas. Let CA, CB, Fig. 24, represent lines drawn upon the paper, parallel to the edges of the knives; and between which all the light would fall if it suffered no inflection; and DE a right line drawn through C, making the angle ACD=BCE, and terminating all the light which falls upon the paper, from the point where the edges of the knives meet. Then $e\,i\,s$, $f\,k\,t$, and $g\,l\,v$, will be three hyperbolic lines, representing the boundaries of the shadow of one of the knives, the dark line between the first and second fringes of that shadow, and the dark line between the second and third fringes of the same shadow. In like manner, $x\,i\,p$, $y\,k\,q$, and $z\,l\,r$, will be three other hyperbolic lines, representing the boundaries of the shadow of the other knife, the dark line between the first and second fringes of that shadow, and the dark line between the second and third fringes of the same shadow. These three hyperbolas, which are similar, and equal to the former, cross them in the points i, k, and l; so that the shadows of the knives are termi-

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[*] An eminent philosopher is of opinion that Newton seems to have considered each fringe as of the nature of a caustic, formed by reflection or refraction, in which the light is every where more condensed than in the collateral spaces, but which is by no means necessarily straight. *Sup. Encyc. Brit.* vol. iii. p. 149.

nated, and distinguished from the first luminous fringes, by the lines $c\,i\,s$, and $x\,i\,p$, till the meeting and crossing of the fringes; and then those lines cross the fringes in the form of dark lines terminating the first luminous fringes on the inside, and distinguishing them from another light, which begins to appear at i, and illuminates all the triangular space $i\,p$ DE s, comprehended by these dark lines and the right line DE. Of these hyperbolas one asymptote is the line DE, and the other asymptotes are parallel to the lines CA and CB.

By measuring the ordinates of these hyperbolas at different points, Newton obtained the following results: $p\,s = 0.31$, $q\,t = 0\ 65$, $r\,v = 0.98$; and adding to these $\frac{1}{2}\,m\,n$, which was the 128th of an inch, or 0.0078, he obtained $n\,p = 0.1828$, $n\,q = 0.3328$, $n\,r = 0.4978$; he measured also the brightest part of the fringes, which was between $p\,q$ and $s\,t$; $q\,r$ and $t\,v$, and next beyond r and v, and found them 0.5, 0.8, and 1.17 inches. Hence he concluded, that these curve lines differed very little from conical hyperbolas.

Newton also found that the shadows of all bodies held in coloured light, were bordered with fringes of the colour of the light in which they were held; that those made in the *red* light were the *largest*, those made in the *violet* the *least*, and those made in the *green* of a *middle* bigness. The fringes with which the shadow of a man's hair were surrounded, being measured across the shadow, at the distance of six inches from the hair, the distance between the middle and most luminous part of the first or innermost fringe on one side of the shadow, and that of the like fringe on the other side of the shadow, was, in the *full red light*, $\frac{1}{37.5}$ of an inch, and in the *full violet* $\frac{1}{46}$. The like distance between the middle and most luminous parts of the second fringes, on either side of the shadow, was in the full *red* light $\frac{1}{22}$, and in the *violet* $\frac{1}{27}$ of an inch; and these distances of the fringes held the same proportion at all distances from the hair, without any sensible variation.

From these observations it was evident, that the rays which formed the fringes in the *red* light, passed by the hair at a greater distance than those which made the like fringes in the *violet;* so that the hair, in causing these fringes, acted alike upon the *red* light or least refrangible rays at a *greater* distance, and upon the *violet* or most refrangible rays at a *less* distance; and thereby occasioned fringes of different sizes, without any change in the colour of any sort of light.

It may therefore be concluded, that when the hair was held in the white beam of light, and cast a shadow bordered with three coloured fringes, those colours arose not from any new modifications impressed upon the rays of light by the hair, but only from the various inflexions by which the several sorts of rays were separated from one another, which before separation, by the mixture of all their colours, composed the white beam of the sun's light; but when separated, composed lights of the several colours which they are originally disposed to exhibit.

As the observations of Newton on inflexion were left in an unfinished state, the subject was resumed by various authors, viz. Maraldi.[*] Dechales,,[†] Mairan,[‡] Dutour,[§] Mr. Brougham,[‖] and Mr. Jordan;[¶] but although the observations of some of these authors are characterised by much ingenuity, they do not seem to have added very materially to our knowledge of this difficult subject.

During Dr. Young's inquiries respecting the theory of light and colours, his attention was directed to the subject of the inflexion of light. In accounting for the fringes which surrounded the shadow of the sides of a small aperture, he conceived that the light nearest its centre will be the least inflected, and that nearest its sides the most; and that another portion of light falling very obliquely on the margin of the aperture, will be copiously reflected in various directions, some of which will, either perfectly, or nearly, coincide in direction with the unreflected light, and having taken a circuitous route, will so *interfere* with it as to cause an appearance of colours. The length of the two tracks, he conceived, will differ the less, as the direction of the reflected light was less changed by its reflexion, that is, in the light passing nearest to the margin; so that the blue will appear in the light nearest to the shadow.

These views respecting the inflexion of light were afterwards confirmed by a very important discovery, which he communicated to the Royal Society on the 24th Nov. 1803. By placing a slip of card in a divergent beam of light, he found that, beside the fringes of colour on each side of the shadow, the shadow itself was divided by similar parallel fringes of smaller dimensions, differing in number according to the distance at which the shadow was observed, but leaving the middle of the shadow always white. These fringes, both *internal* and *external*, are represented in Fig. 25. where ABCD is the shadow with its *internal* fringes. Dr. Young now considered that these fringes were the joint effects of the portions of light passing on each side of the slip of card, and inflected into the shadow; *for when he placed a little screen either before the slip of card, or a few inches behind it, so as either to receive the edge of its shadow, or the margin of the card, all the fringes which had before been observed in the shadow on the wall immediately disappeared*, although the light inflected on the other side was allowed to retain its course, and although this light must have experienced any modification that could have been produced by the proximity of the other edge. By placing the screen at a greater distance behind the slip of card, it was necessary to plunge it more deeply into the shadow, in order to extinguish the parallel lines; for, in this case, the light diffracted from the edge of the card, entered farther into the shadow on its way to form the fringes. In order to show that the extinction of the fringes was not occasioned by want of light, arising from the interposition of the screen, Dr. Young reduced the intensity of the light to one-tenth, or even one-twentieth of the light, and found that the fringes were seen distinctly in this attenuated light when the screen was not interposed. Hence Dr. Young obtained an *experimental demonstration of the law of interference:* a law which, though neglected at the time by many philosophers, and opposed by the ignorance and jealousy of others, has, like every other production of genius, triumphed over all opposition, and is now universally admitted as a general principle in physical optics.

In applying the same principle to the crested fringes discovered by Grimaldi, as produced by the shadow of an object with a rectangular termination, as shown more correctly in Fig. 26. Dr. Young found, that when a screen was placed within a few inches of the object, so as to receive only one of the edges of the shadow, the whole of the fringes disappeared; and if, on the contrary, the rectangular point of the screen was opposed to the point of the shadow, so as barely to receive the angle of the shadow, or its extremity, the fringes remained undisturbed. Dr. Young found, that by the theory these curves ought to be equilateral hyperbolas, whose axes coincide with the outlines of the shadow, and the asymptotes nearly with the diagonal line.

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[*] *Mem. Acad. Par.* 1723.

[†] *Curs. Mathemat.* vol. iii. p. 726.

[‡] *Mem. Acad. Par.* 1738, p. 53.

[§] *Mem. des Savans Etrangers,* tom. v.

[‖] *Phil. Trans.* 1796, vol. lxxxvi. p. 227; and 1797, vol. lxxxvii. p. 352.

[¶] *New Observations concerning the Inflexions of Light,* &c. Lond. 1795.

In order that the reader may have a better idea of the law of interference, let us suppose that two portions of light interfere with one another, the lengths of whose paths are exactly the same. In this case they will form a fine bright fringe, having an intensity greater than that of either portion. Then if d is the difference in the lengths of the paths that produces another bright fringe, similar bright fringes will be formed when the differences in the lengths of the paths are $2d$, $3d$, $4d$, $5d$, &c. But it is found from experiment, that if the portions of light interfere at intermediate points, or when the differences in the lengths of their paths are $\frac{1}{2}d$; $d+\frac{1}{2}d$; $2d+\frac{1}{2}d$; $3d+\frac{1}{2}d$, &c. instead of adding to one another's intensity, they destroy one another, and produce black.

This beautiful law is not easily explained upon the Newtonian theory of emission. Dr. Young, though hostile to this theory, has remarked, that the law of interference may be reconciled to the doctrine of emission, if we suppose, with Newton, that the projected corpuscles of light excite sensation by means of the vibrations of the fibres of the retina and of the nerves. We may then imagine that such vibrations must be most easily produced by a series of particles following each other at equal distances, each colour having its appropriate distance in any given medium; and it will be demonstrable, that a second series of similar particles, interfering with them in such manner as to bisect the intervals, will destroy their influence in producing a vibratory motion, each succeeding particle meeting the fibre at the instant of its return from the excursion generated by the stroke of the preceding particle. Hence the motive effect of the stroke will be annihilated. On the Huygenian theory, however, the law of interference is satisfactorily explained.

"In the undulatory theory," says Dr. Young, "the analogy between the laws of interference and the phenomena of the tides, and the effects of the combination of musical sounds, is direct and striking. The existence of an undulation of an elastic medium depends on the recurrence of opposite motions, alternately direct and retrograde at certain equal distances, in the same manner as a series of waves consists in a number of alternate elevations and depressions, and the succession of the tides in a number of periods of high and low water. The spring and neap tides, derived from the combination of the simple solar and lunar tides, afford a magnificent example of the interference of two immense waves with each other; the spring tide being the joint result of the combination when they coincide in time and place; and the neap, when they succeed each other at the distance of half an interval, so as to leave the effect of their difference only sensible. The tides of the port of Batsha, described and explained by Halley and Newton, exhibit a different modification of the same opposition of undulations; the ordinary periods of high and low water being altogether superseded, on account of the different lengths of the two channels by which the tides arrive, affording exactly the half interval which causes the disappearance of the alternation. It may also be very easily observed by merely throwing two equal stones into a piece of stagnant water, that the circles of waves which they occasion obliterate each other, and leave the surface of the water smooth, in certain lines of a hyperbolic form, while in other neighbouring parts the surface exhibits the agitation belonging to both series united. The beating of two musical sounds, nearly in unison with each other, appears also to be an effect exactly resembling the succession of spring and neap tides, which may be considered as the beatings of two undulations, related to each other in frequency as 29 to 30; and the combination of these sounds is still more identical with that which this theory attributes to light; since the elementary motions of the particles of the luminiferous medium are supposed to be principally confined to the line of direction of the undulation, while the most sensible effects of the waves depend immediately on their ascent and descent, in a direction perpendicular to that of their progressive motion."

The subject of the inflexion of light has received very important accessions from the labours of M. Fresnel. In place of using a small hole, he employed a lens of very short focal length, which collected the solar rays into its focus, from which they diverged as if they had proceeded from a small aperture. The fringes which surrounded bodies placed in this light he examined by an eye-glass furnished with a micrometer, instead of receiving them upon a white surface, and in this way he was able to determine their breadths, even to the one-hundredth or two-hundredth part of a millimetre. He thus followed the external fringes to their origin, and by means of a lens of a short focus he perceived the third fringe at the distance of less than the one-hundredth part of a millimetre from the edge of the inflecting body. M. Fresnel likewise found, that the inflexion of the passing light was influenced by the distance of the radiating or luminous point from the inflecting body, as appears from the following experiments:

Distance of the radiating point from the inflecting body.	Distance behind the body where the inflexion was measured.	Angular inflexion of the red rays of the first fringe.
100 millimetres	1 metre	12′ 6″
6 metres	1 metre	3 55

Hence it follows, that the passing rays suffer a less degree of inflexion, in proportion as the inflecting body is placed at a greater distance from the radiant point.

While the distance of the radiant point remained fixed, M. Fresnel measured the inflexion of the same fringe at different distances behind the inflecting body, and he found that the *successive positions of the same fringe were not in a straight line, but formed a curve, whose concavity is turned towards the inflecting body.* The lines which formed the different positions of the fringe of all the orders of colours were found to be hyperbolas, having for their common foci the radiating point and the edge of the inflecting body. In some of the results the *sagitta* of curvature was about the 25th part of an inch, or nearly 50 times greater than the error of observation.

Another method of viewing the fringes employed by M. Fresnel consisted in placing two metallic mirrors, inclined to one another so slightly that their surfaces were nearly in the same plane. When the eye was placed behind these mirrors and at the distance of eight or ten feet from the luminous point, so that it observed the image of that point reflected from each mirror, then, by using a lens of a short focus, he saw between the places of the two images a series of coloured fringes perpendicular to the line forming the images.

From numerous experiments on these fringes, M. Fresnel found that the length of a wave, or undulation, for *Red* light, or the value of *d*, (see p. 685.) was about the $\frac{638}{1000000}$dth part of a millimetre.

The *exterior* fringes formed by inflexion had been ascribed, both by Dr. Young and M. Fresnel, to the interference of the direct rays with those which were reflected from the margin of the reflecting body. This explanation has, however, been found to be insufficient by M. Fresnel, as the real place of the fringe is sometimes $\frac{17}{100}$dth of a millimetre different from what it should be upon that supposition; and, at any rate, if the hypothesis were correct, the intensity of the fringes would be affected by the extent and the curvature of the margin of the inflecting body, which is not found to be the case. M. Fresnel has, therefore, been obliged to admit, that the rays which pass at a sensible distance from the inflecting body are made to deviate from their primitive direction, and concur also in the production of the coloured fringes.

In pointing out the application of the Huygenian theory to the phenomena of inflexion, M. Fresnel supposes that C Fig. 27. is the radiant point, and AMF a wave which, when it arrives at A, is intercepted by the opaque inflecting body AG. He then conceives the wave divided into an infinity of small arcs A m', m' m, m M, M n, n n', n' n'', and in order to have the intensity of the wave at any point P of any of its succeeding positions BPD, he determines the resultant of all the elementary waves which each of the above portions of the primitive wave will propagate to P by acting alone. These elementary waves have their intensities sensibly equal when their direction does not deviate much from the perpendicular. When the waves are sensibly inclined to the perpendicular, as EP, FP, IP, and the point P is supposed to be distant by many undulations from the wave AE, let EF, FI, be of such a length that EP — FP, and FP — IP, are equal to a semi-undulation. Then, on account of the obliquity of these undulations, and the smallness of a semi-undulation in respect to their length, these two arches will be almost equal, and the rays which they send to the point P will be almost parallel, so that, on account of the difference of a semi-undulation which exists between the corresponding rings of the two arches, their effects will mutually destroy one another. Hence M. Fresnel supposes that all the rays which the different parts of the primitive wave AE send to the point P are of equal intensity, since the only rays for which this hypothesis is incorrect have no sensible influence on the quantity of light which it receives.

When the opaque body AG, Fig. 28. is so narrow that we can distinguish the fringes in the *exterior* of its shadow at the distance AB, let C be the radiant point, and BD the white ground which receives the fringes. We may then conceive the primitive wave KL divided into the small arcs Am, mm', $m'm''$, &c. Gn, nn', $n'n'$, $n''n'''$, &c. so that the rays drawn from the point P in the interior of the shadow differ in their length by a semi-undulation. Then all the small waves propagated to P by the elements of each of those arcs will be in complete discordance with the elementary waves which emanate from the corresponding parts of the two arches between which it is comprised, so that if all these arches were equal, the rays which they would propagate to P would destroy each other, with the exception of the extreme arch m A, whose rays will preserve the half of their intensity, or the half of the light propagated by the arch mm'', with which they are in complete discordance, being destroyed by the half of that of the preceding arch $m''m'$. These arches are sensibly equal when the rays which meet at the point P are sufficiently inclined to the perpendicular, in which case the resulting wave corresponds nearly to the middle of mA, the only arch which produces a sensible effect, and is behind by a quarter of an undulation in relation to the elementary wave, which set out from the margin A of the reflecting body. As the same thing takes place relatively to the other part G n of the incident wave, the degree of accordance or discordance between the luminous vibrations which show themselves at the point P, will be determined by the difference in the lengths of the two rays s P and t P, which emanate from the middle of the arcs A m and G n, or, what is the same thing, by the difference between the two rays AP and GP, which set out from the edges of the inflecting body. Hence, when the interior fringes are sufficiently distant from the margins of the geometrical shadow, we may suppose that the inflecting waves have their centres in the very edges of the inflecting body.

We regret that we cannot follow M. Fresnel throughout the whole of his able investigation. Our limits will not permit us to do any thing more than present our readers with some of the leading formulæ which he has deduced. Calling

x = Breadth of any fringe of homogeneous light.
λ = The length of an undulation.
a = Distance of the inflecting body from the radiant point or aperture.
b = The distance of the paper which receives the fringe behind the inflecting body.
v = The velocity of light in its oscillations.
n = The value of v corresponding to the *maximum* and *minimum* of the fringes.

Then he finds,

$$x = v\sqrt{\frac{\frac{1}{2}(a+b)\,b\,\lambda}{a}}, \text{ or for the maximum and minimum. } \quad x = n\sqrt{\frac{\frac{1}{2}(a+b)\,b\,\lambda}{a}}.$$

Here the radical quantity is precisely the distances between the margin of the geometrical shadow, and the point which corresponds to a difference of a quarter of an undulation between the direct ray, and the ray which sets out from the margin of the inflecting body. If we then substitute in place of n its value corresponding to the minimum of the first order, that is, the darkest part of the obscure fringe of the first order, we have,

$$x = 1.8726\sqrt{\frac{\frac{1}{2}(a+b)\,b\,\lambda}{a}}.$$

These formulæ are suited to the hypothesis of M. Fresnel. But if we suppose, with Dr. Young, that the fringes are produced by the interference of the direct rays with those reflected from the margin of the reflected body, and suppose also that the reflected rays experience a retardation of a semi-undulation, then we shall find that

$$x = \sqrt{\frac{2\,(a+b)\,b\,\lambda}{a}} \text{ or } x = 2\sqrt{\frac{\frac{1}{2}(a+b)\,b\,\lambda}{a}}.$$

Now the values of x, on these two hypotheses, are as 2 to 1.8726, so that we may determine which of them agrees best with experiment.

M. Fresnel has made this comparison, and has found the new hypothesis more consistent with observation than the other. Hence we may confidently conclude, that the formation and position of the exterior fringes are satisfactorily explained by considering them as produced by the interference of an infinity of elementary waves which emanate from a primitive wave, when partly interrupted by an opaque body.

M. Fresnel has remarked it as an interesting result of his formula, that the values of x are not proportional to the values of b, but to the ordinates of a hyperbola of which the values of b will be the abscissæ. Hence it follows from this theory, that the points of the same intensity, in relation to the margin of the geometrical shadow, do not form a straight line by varying b, but a hyperbola, and this is the case both for the exterior and the interior fringes *.

The important discovery of Dr. Young, that the interior fringes disappeared by the interposition of a screen, was extended by M. Arago, who found that the same effect is produced by a transparent screen of sufficient thickness, and that thin screens only transfer the fringes from the side where they are formed. When a transparent screen is placed on each side of the inflecting body, the effect is equal to the difference of the transferences which each of them would have produced separately. When the thickness and the refracting power of the screen is known, the quantity of this transference may be computed from principles deduced from the undulatory theory. This method has been employed by MM. Arago and Fresnel, for measuring the refractive powers of gases with great exactness.

It follows from the law of interference as given by Dr. Young, that the velocity of the rays in glass will be less rapid than in air, in the ratio of their refraction, so that if one of two rays before their interference is transmitted through a very thin plate of glass, and then allowed to interfere with the other ray, it will not produce the same coloured fringe that it would have done had the plate of glass not been interposed, but there will be some other ray with which it will interfere in another place, and produce the coloured fringe. By observing, therefore, the displacement of the coloured fringes produced by a given plate of glass, we may find the refractive power of this plate MM. Arago and Fresnel have employed this method in measuring differences of refraction which could not be determined by any other means.

An account of a series of very splendid and interesting experiments on the inflexion of light, has been recently published by M. Fraunhofer of Munich, under the title of *Neue Modifikation des Lichtes durch gegenseitige Einwirkung und Beugung der Strahlen, und Gesetze derselben.*† As these experiments are entirely unknown in this country, and apparently not even in France, we shall lay before our readers a fuller account of them than might otherwise be thought necessary.

In these experiments, M. Fraunhofer employed a heliostate for giving a fixed direction to the solar ray, and he examined all the phenomena through a telescope mounted upon a large and accurate theodolite, by means of which he measured the deviation of the inflected light. The object glass was 20 lines in diameter; its focal length was 16.9 inches, and its magnifying power from 30.4 to 110. The heliostate was placed 38 feet 7½ inches French measure from the centre of the theodolite. The diameters of the apertures were measured by a micrometer microscope, which indicated distinctly the two hundred thousandth part of an inch, and sometimes even half that quantity.

Having directed the telescope to the aperture of the heliostate, so that the aperture was bisected by the wire of the micrometer, a very narrow aperture, such as that shown at A, Fig. 1. was placed before the object glass. There was then seen in the middle of the field a *white* band $L^{I}KL^{I}$, Fig. 3. which became *yellow* towards L^{I}, and L^{I} where it was *red*. On both sides of K, beyond L^{I}, L^{I}, were other two spaces $L^{I}\,L^{II}$; $L^{I}\,L^{II}$, which displayed all the ordinary colours of the spectrum in great vivacity, the *indigo* beginning near L^{I}, and followed by *blue*, *green*, *yellow*, terminating with *red* at L^{II}, L^{II}. To the right of L^{II} a second space $L^{II}\,L^{III}$, equal to the preceding, displayed another spectrum, but with colours much less lively, being *blue* at L^{II}, then *green*, *yellow*, and then *red* at L^{III}. To the right of this a similar spectrum $L^{III}\,L^{IV}$ was formed, and many others of a similar nature in succession, their boundaries becoming less defined. These spectra increase in magnitude as the aperture is diminished, and when formed in this manner by a single aperture, they are called *External* spectra. In this way M Fraunhofer obtained the measures in the following Table.

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[*] The hyperbolic form of the consecutive points of the same fringes was discovered by Dr. Young, and is described in his *Lectures on Natural Philosophy*, vol i. p. 287. Fig. 442.

[†] A very excellent abstract of this paper will be found in the *Bibliotheque Universelle*, for January and February, 1822, tom. xix. pages 3 and 73; but it is not easily understood in consequence of the principal figures not being given.

N°.	Diameter of the Aperture, in Paris Inches.	L^{I}	L^{II}	L^{III}	L^{IV}	Arithmetical Mean, L.	Product of the Aperture of the Arch L.
1	0.11545	37″.58	1′ 15″.5	1′ 53″		37″.66	0.0000210
2	0.06098	1′ 11 .6	2 32 .7	3 31 .7	4′ 44″.7	1′ 11 .17	0.0000210
3	0.03690	1 57 .1	3 53 .3	5 48 .3		1 56 .6	0.0000209
4	0.02346	3 4	6 7 .7	9 16 .3		3 4 .43	0.0000210
5	0.01237	5 48 .5	11 38	17 26 .5	23 14 .7	5 48 .7	0.0000209
6	0.01210	6 —	12 1	18 14	24 9	6 1 .84	0.0000212
7	0.01020	6 56	13 56	20 54		6 57 .3	0.0000206
8	0.00671	11 6	22 12 7	33 14	44 35	11 6 .4	0.0000217
9	0.00642	11 11	22 18	33 43	44 58	11 12 .2	0.0000209
10	0.00337	21 3	42 16	1° 4 —		21 10 .3	0.0000207
11	0.00308	23 31	47 6	1 10 43		23 32. 7	0.0000211
12	0.00218	33 30	1° 7 40			33 40	0.0000213
13	0.00215	35 24 .7	1 10 16			35 17	0.0000220
14	0.00114	1° 4 53 .53				1° 4 53	0.0000215

From these results M. Fraunhofer concludes,

1. *That the angles of deviation of light passing through different apertures, are inversely as the width of the apertures.*

2. *That the distances of the fringes of homogeneous light from the middle* K *of the luminous band are in an arithmetical progression, whose difference is equal to the first term.*

M. Fraunhofer now proceeds to examine the phenomena of inflexion, where the margins of the aperture are in different planes, or in planes distant from one another. When in this case, the apparent aperture is reduced from 0.02 to 0.04 of an inch, the *spectra* are the same as when the margins of the aperture are equidistant from the observer; but if the apparent aperture is gradually diminished below 0.07, the spectra on the same side as the margin of the aperture nearest the observer *expand horizontally more than those on the other side*, so that the phenomena cease to be symmetrical on each side of the centre of vision. When the aperture becomes very narrow, the spectra on the side already mentioned become *double*, and then *quadruple*, of those which remain nearly stationary on the other side. This disappearance takes place in the following manner: The fifth spectrum expands almost instantaneously over the whole visible space, and is soon invisible. The same thing happens to the fourth and to the third in succession. During this time the spectra on the other side of the axis are not sensibly altered; but when the first, or those which vary in magnitude, have all vanished, the latter disappear, not successively, but all at once, when the two margins which form the apparent aperture have excluded by their approach the whole of the incident light.

When the light arrives at the heliostate by a circular aperture from 0.04 to 0.08 of an inch in diameter, and when a square aperture is placed before the telescope, a luminous cross appears, *having the same colours in the vertical as in the horizontal branch*, and fainter spectra in the four angles, as shown in Fig. 4. If the aperture is rectangular, and higher than it is wide, the *spectra on the horizontal and vertical branch have not the same dimensions*, those in the vertical branch being smaller in the inverse ratio of the height to the length.

If the aperture in front of the telescope is *round*, the concentric coloured rings of Newton, but without any central black spot, appear in the field of the telescope. These rings increase in diameter as the circular aperture diminishes.

The following Table contains the results of M. Fraunhofer's measurements of these rings.

From these measures M. Fraunhofer concludes,

1. *That the diameters of the coloured rings produced by circular apertures are inversely as the diameters of the apertures:*

2. *That in the same rings the radii of curvature of the red margin of the different rings, reckoning from the centre, follow an arithmetical progression, whose difference is* smaller *than the first term.*

No.	Diameter of the Aperture, in Paris Inches.	L^{I}	L^{II}	L^{III}	L^{IV}	L^{V}	Arithmetical Mean of the Differences, L.	$L^{1}\gamma$	$L\gamma$
1	0.10426	53″ 8	1′ 36″.3	2′ 16″	2′ 50″.5		41″.6	0.0000272	0 0000210
2	0.06713	1′ 22 .3	2 27	3 30	4 32. 3		1′ 3 .3	0.0000268	0.0000206
3	0.05701	1 48 .8	3 17 .3	4 46 .8	6 15 .5	7′ 47″.7	1 29 .7	0.0000264	0.0000217
4	0 03997	2 12 .7	4 2 .9	5 55 .1	7 48 .6	9 40 .9	1 52	0.0000257	0.0000217
5	0 03791	2 15 .7	4 8 .5	6 6 .3	8 5 .1		1 56 .5	0.0000249	0 0000214
6	0 03318	2 41 7	4 52 .4	7 6 .4	9 18 .7	11 32	2 12 .6	0.0000260	0.0000213
7	0.02682	3 13 .1	6 1 .4	8 49 .7	11 42		2 49 .6	0 0000251	0.0000223
8	0.02318	3 49 .4	6 57 .8	10 14 .5	13 23 .6		3 11 .4	0.0000258	0.0000215
9	0.02237	3 54 .7	7 9 .4	10 24 .1	13 40 .5		3 15 .3	0.0000255	0.0000212
10	0.02134	4 3 .6	7 24 .5	10 56 .4	14 15 .4		3 20 .6	0.0000252	0.0000208
11	0 01824	4 45 .5	8 51 .3	12 54 .9	17 3 .5		4 6	0.0000252	0.0000217
12	0.01746	5 3	9 19 4	13 22 9	17 52		4 16 .3	0.0000257	0.0000217
13	0.01238	6 55 .5	12 57 5	18 48 .6			5 56 .5	0 0000249	0.0000214
14	0 00922	9 27 .3	17 35 .4	25 34 5			8 3 .6	0.0000254	0.0000216

In place of an aperture bounded by the edges of metallic plates, M. Fraunhofer employed one of a different kind. Having covered a piece of glass with two or three folds of gold leaf, he drew upon it with a very fine point either a straight line or a circle, free of any burr at the edges. When the aperture of a circular line was used, circular rings were formed, having the same colours as those produced by a circular aperture, but of different diameters. Their diameter was now independent of that of the circle, but depended only on the *width of the circular line*, so that when the width of the circular line became equal to the radius of a common circular aperture, the phenomena were the same as in the last Table. Hence, calling w the width of the circular line, we shall have

$$\frac{0.0000211}{w}, \text{ and } 2.\frac{0.0000211}{w}, \; 3.\frac{0.0000211}{w}, \text{ \&c.}$$

for the semidiameters of the 1st, 2d, and 3d rings produced by a circular line.

When an arch of the circular line was intercepted, for example, an arch of 220°, then the coloured rings were not complete, but wanted two opposite segments, as shown in Fig 5. at AB, CD, each being = 40°. and in general the opposite coloured arches AC, BD, are exactly equal to the number of degrees of the circular line not intercepted.

In order to determine the effect produced by the concourse of a great number of rays equally inflected, M. Fraunhofer placed before his telescope a series of parallel and equidistant wires. In order to form this system of wires, he placed two screws parallel to each other on the opposite sides of a frame, and having 160 threads in a French inch; and he placed a wire in each thread, for the purpose of insuring their exact parallelism. The threads had a diameter of 0.0002021 of an inch, and were separated by intervals of 0.003862 of an inch. A pencil of the solar rays was then admitted upon the object glass of the telescope, through a vertical aperture 2 inches high and 0.001 of an inch wide, and the frame of wires was placed before the object glass, so that no other light could be admitted but what passed between them.

In looking through the telescope, M. Fraunhofer was delighted with a sight equally new and interesting, and which he has attempted to illustrate by Fig. 1. At A is seen the luminous aperture as distinctly terminated, and having the same shape, as if no wires had been interposed. To the right and left of A are two spaces AH′, AH′, *absolutely deprived* of light. Beyond this, on each side, are two equal and similar spectra H′C′, H′C′, as brilliant as those produced by a good prism, H′ being the violet, and C′ the red extremity. Beyond this, from C′ to H″, and from C′ to H″, there is a space as dark as the former. Then succeeds another spectrum H″ C″, having double the width of the first, and the colours in the same order, but much fainter. To this spectrum succeeds a *third* to the right of C″, without the intervention of any black space; but a part of the violet rays mix with the red of the spectrum. It is more extended than the second, but the colours are less lively. A *fourth* spectrum follows, whose blue border mixes with the third spectrum, and its red border with the fifth spectrum. Other spectra, more expanded and dilated, follow both on the right and on the left; and our author has been able to distinguish no fewer than thirteen on each side of the central line A.

When the eye-glass is adjusted to distinct vision of the aperture near the heliostate, the frame of wire being removed, Fraunhofer observed, after the frame of wires was replaced, the lines and bands which he had discovered in the common solar spectrum. (See p. 678.) Hence he was enabled to determine very exactly the laws by which the inflected spectra were formed; for the lines were grouped in the same manner in both kinds of spectra, which differed only in the relative proportions of the coloured spaces. M. Fraunhofer has given the name of *mean spectra* to those produced by the parallel wires; and he calls them *perfect* when the lines and bands are distinctly seen, and *imperfect* when the lines are not perceived, in consequence of the small number of inflected rays.

M. Fraunhofer repeated the same experiments with wires stretched in the threads of screws, which had 340 to the inch. He employed also gilt plates of glass, on which he had traced parallel lines, very delicate and very near to each other, and he found that these glasses gave the same spectra as the wires. By thus varying the experiments, he found that the magnitude of the mean spectra depend neither on the width of the intervals between the wires, nor on the diameter of the wires themselves, but on these two quantities taken collectively, or on the distances from the middle of two adjacent intervals; the effect being exactly the same, whether the wires were large and the intervals small, or whether the intervals were large and the wires small, provided that the distance between the centres of two contiguous intervals remained the same. Hairs produced the same effect as wires.

When the wires are large, and the intervals narrow, but the distance of the centres of the intervals considerable, then the *mean spectra* cease to appear to the right and left in the field of view; but others of different widths, but without the lines and bands of the prismatic spectrum, are seen, which resemble the *external spectra* already described. Sometimes part of the *external spectra* coincide with the *mean spectra*, and alter their purity The *perfect mean spectra* consist of homogeneous light, and by examining them with a prism, it is easy to find beyond the third spectrum, where they overlap one another, and mingle their tints.

M. Fraunhofer next proceeds to take exact measures of the distances of each of the lines H' G' F', &c. from the central line A, and to ascertain how these distances are related to the diameters of the intervals and the wires. From ten sets of experiments, in which d, the diameter of the wires, varied from 0.001324 of an inch to 0.022486, and i, the interval between the wires, varied from 0.000628 to 0.002878, he deduced the following laws.

1. *If by means of two different frames of wires, each composed of wires of the same diameter, and with equal intervals, we inflect a great number of rays, which pass through the intervals of the wires, this inflexion, joined to the mutual influence of the inflected rays, generates coloured spectra, whose width and distance from the axis of vision are in the inverse ratio of the spaces reckoned from the middle to the middle of the intervals between the wires, that is, in the inverse ratio of the quantity* $d+i$.

2. *In the perfect mean spectra, the deviations of rays of the same colour in spectra, placed symmetrically on both sides of the axes, follow an arithmetical progression, whose difference is equal to the first term.*

When the light which falls upon the object glasses has passed through two equal frames of wires, the spectra produced have the same magnitude as if there had been only one; but if the two frames of wires are unequal, the distance of the spectra to the right and left of the axis is the same as if the closest frame of wires had alone been used.

M. Fraunhofer's next object was to ascertain the mutual influence of *two* or *three* inflected rays; and in order to do this, he placed before one of his wire frames two screens, situated in the same vertical plane, and by means of whose rectilineal edges he could cover all the intervals of the wire frame, excepting *One*. When this was done, he found that the spectra were, as might have been expected, the very same as the *external* ones formerly described. When *Two* intervals of the wire frame were open, the *imperfect mean spectra* were then seen, along with the external ones, occupying a space from M^{I} to M^{IV}, Fig. 2. exactly equal to L^{I} L^{I}, in the spectrum shown in Fig. 3. all the spectra to the right and left hand of M^{IV} M^{IV}, being exactly the same as in Fig. 3. Each of the imperfect mean spectra, M^{I} M^{II}, &c. is composed of the same colours and in the same order as the spectrum L^{I} L^{I}, of Fig. 3. When *Three* intervals were open, a third kind of spectra, which he calls *internal*, were seen, and which appear along with the other two kinds. They occupy the space between M^{I} and M^{I}, in Fig. 2. and are two in number, and have the same colours as the other spectra. When *Four* intervals were open, all the three classes of spectra were seen, but the internal ones, now *three* in number, were sensibly narrower than when only two intervals were open. With *Five* intervals open, the *internal spectra*, now *four* in number, were narrower still, and the *mean spectra* altered a little. With *Six* intervals open, the *external spectra* were smaller than with *five;* with *seven* smaller than with *six;* and so on, till at last they can no longer be distinguished, and we see only a bright and colourless line, such as would be seen if the wire frame was not interposed between the heliostate and the object glass. After measuring the angles which these spectra form on both sides of the axis, M. Fraunhofer draws the following conclusions:

1. *When we use the* same *wire frame, but vary the intervals, or the number of inflected rays, the distances of the* internal *spectra from the axis of vision, and their magnitude, are inversely as the number of rays admitted, that is, of the number of free intervals setting out from the number* 3.

2. *When we use* different *wire frames, the number of inflected rays remaining the same, the distances of the* internal *spectra and their magnitudes are in the inverse ratio of the quantity* $i+d$, *that is, of the distance between the middle points of two adjacent intervals.*

3. *In the* internal spectra *the distances from the axis follow an arithmetical progression, whose difference is equal to the first term.*

M. Fraunhofer has also found that the magnitude of the *mean imperfect spectra*, and their distances from the axis, vary as the quantity $i+d$ in different wire frames; though they differ greatly from those produced by round or narrow apertures, with respect to the series of distances between the axis of vision and the different coloured rays.

In order to determine the effects produced when the inflexion takes place in different inflecting media, M. Fraunhofer placed his wire frames in glass vessels, with parallel sides, and containing different fluids, such as *water, oil of turpentine*, and *oil of anise seeds*. In all these cases he found the deviation of the spectra as much greater in these media as the refracting power was greater; hence, by multiplying the deviations found by experiment by the index of refraction from any ray in a given medium, we obtain the angle which would have been observed in air; that is,

With the same wire frame plunged in different media, the sines of the angles formed by rays made to diverge by inflection in each of these media, are in the inverse ratio of the indices of refraction for each medium. This law is true both for the internal and the external spectra, but our author is not certain if it is applicable to the *mean imperfect spectra*.

When a number of inflected rays are produced by reflexion from a plate of gilded glass, having a great number of opaque and narrow intervals traced on the silvered side with a fine point, and when this plate received the rays from the heliostate, and reflected the light to the object glass, all the phenomena were produced in the same manner as when the wire frame was used, the spectra and their distance from the axis increasing as the angle of incidence upon the striped mirror was diminished.

The most curious phenomena observed by M. Fraunhofer, were obtained by the interference of pencils of rays inflected by round and quadrangular apertures. He first examined the effect of two pencils of rays passing through two circular apertures perforating a thin plate of brass. The diameter of each aperture was 0.02227 of an inch, and the distance of their centres was 0.03831 of an inch. When the aperture near the heliostate was round, and the plate of brass placed before the telescope, the extraordinary appearance shown in Fig. 6. was observed. This figure consists of 65 elliptical spectra, distributed in four concentric rings, the largest of which contains 28 spectra, the next 20, the third 12, and the fourth 5 contiguous spectra occupying the centre, which is perfectly white. The arrangement of these spots is symmetrical on the right and left side of the circle. From the upper and lower side of the circle diverge three large bands, the breadth of each of which is about one-third of the diameter of the circle. These bands, forming a St. Andrew's cross, are each covered with three rows of white elliptical spots upon a white ground.

When the distance of the two apertures is increased, and their diameter remains the same, the spectra become more numerous, and the angle formed by the bands of the St. Andrew's cross become smaller.

If we increase the diameter of the apertures without changing the distance of their centres, the diameters of the coloured rings which contain the spots diminish in the same ratio, but the spectra or spots which compose them remain at the same distance from each other; whence it follows that the number of spots in each ring diminishes.

If we perforate a plate of metal with three, and afterwards with four circular apertures placed in a row like the two already mentioned, the middle spectrum in the circular central spot separates more and more from the adjacent ones, and becomes narrower, a modification analogous to that which arises from the interference of two, and afterwards of three rays inflected by narrow longitudinal apertures. The spectra presented by each spot becomes also more narrow, and their colours more lively.

When four apertures are arranged, so as to correspond with the four angles of a square, the phenomena experience a considerable change, as shown in Fig. 7. The elliptical coloured spots become more numerous, there being no fewer than 48 in the largest of the concentric rings; and on the fourth, which occupies the centre of the large image, nine of a square form, and with rounded angles, arranged in threes, so as to represent a square with nine divisions. This central square is white in the middle, and red at the edges. From the top of the great image there radiates three bands *aa*, *bb*, *cc*, forming only a fourth part of the cross. If we leave the diameters of the four apertures the same, and increase the square which they form, the central spot will then divide itself into a greater number of small squares; an effect which is analogous to that observed in the images of two longitudinal apertures whose width has been increased.

If the plate of metal is perforated with several equal circular apertures, corresponding with the angles of a number of contiguous and equal squares, the image remains nearly the same as if there had been only four apertures, only the spectra, particularly the middle ones, appear as much more distant from each other, and as much more vivid, as the number of apertures is increased. This modification is analogous to that which takes place when several circular apertures are arranged in the same straight line.

When the apertures to the number of three are placed at the three angles of an equilateral triangle, the appearance is what is represented in Fig. 8. The coloured elliptical spots are much more numerous, and are arranged in five concentric rings, the outermost of which contains 54. Their dimensions are nearly equal; but the central spot, and the six which surround it, and touch one another reciprocally, are of a circular form, excepting the slight flattening at their points of contact. The central spot is white, and reddish at the edges, and the others are white near the centre, and red towards the edges. If, when the apertures remain the same, we enlarge the triangle which they form, a greater number of spots appear in the centre; but their size is diminished. When a great number of apertures are made, so as to form the angles of a number of contiguous equilateral triangles, the spectra separate much; and the six round spots which encircle the central one are transformed into six symmetrical spectra with brilliant colours, but no longer contiguous. The other spectra also become narrower and more brilliant.

The most beautiful of all the phenomena observed by M. Fraunhofer, is that which we have represented in Fig. 9. which contains only a quadrant of the circular image. This singular effect is produced, by transmitting the light of a circular aperture through two equal wire frames placed one upon the other, so that the wires cross one another at right angles. In this figure the spectra are no longer elliptical spots, but narrow bands about a line in width, and varying in their lengths from five lines to five inches. They all radiate directly from the centre, but at the same time form varied and symmetrical groups in each sector of 45°. Each of these bands represents a perfect spectrum, whose violet extremity is nearest the centre, and its red extremity next the circumference of the figure. In some places the spectra touch, and even overlap one another, but the greater number are insulated; and the effect of the whole upon a deep black ground is uncommonly splendid.

When different wire frames are crossed in the same manner, the distances of the spectra from the centre, and their magnitudes, are in the inverse ratio of the distances between the centres of any two contiguous square apertures arising from the crossing of the wires. The spectra produced in these cases are *perfect mean spectra*, and have neither lines nor bands.

If two unequal wire frames are crossed at right angles, the magnitude and inclination of the spectra are modified only in one direction, and in the inverse ratio of the distance, between the centres of any two contiguous square intervals.

If the wire frames are crossed, so as to form rhombic spaces, the spectra are still symmetrical; but their position deviates from that formerly described, in proportion as the angles of the rhombs become more acute.

In concluding his very interesting memoir, M. Fraunhofer remarks, that all these varied phenomena may be explained upon the undulatory system; and that the same system furnishes an explanation of the lines and bands which are found in the ordinary prismatic spectrum.

CHAP. V.

ON THE COLOURS OF THIN AND THICK PLATES, DOUBLE PLATES, MIXED PLATES, AND STRIATED SURFACES.

In all the phenomena of reflexion and refraction from plates with parallel surfaces which we have hitherto described, we have supposed their thickness to be such as to reflect or transmit white light. Mr. Boyle first observed the colours of bubbles of the essential oils, spirit of wine, turpentine, and soap and water; and he succeeded in blowing glass so thin as to exhibit the same tints. In 1672, Dr. Hooke exhibited to the Royal Society a soap bubble with all its colours; and he afterwards succeeded in forming plates of mica so thin, as to exhibit a uniform tint over every part of their surface. Analogous phenomena had also been observed by Lord Brereton, in 1666, in the colours produced by thin oxidated films which appear upon the surface of glass acted upon by the weather. Sir Issac Newton afterwards discovered that analogous colours might be produced by thick plates. Mr. Nicholson observed colours in the reflexion of light from two glasses of unequal thickness; Dr. Young discovered them in mixed plates; and Dr. Brewster found them in plates of parallel glass of equal thickness, when slightly inclined to one another.

SECT. I.—*On the Colours of Thin Plates.*

THE best method of exhibiting the colours of thin films of soap and water, is to dip the mouth of a wine-glass in the fluid, and when a film of the soapy water is stretched over it, and held in a vertical position, its upper edge becomes nearly black, while the lower parts are divided by horizontal lines into a series of coloured fringes, as represented in Plate CCCCXXXIII. Fig. 29.

The colours of a thin plate of air may be easily exhibited, by pressing together the surfaces of two glass prisms that have not large refracting angles. At the place of contact various fringes of coloured rays will be seen, both by looking at the light reflected from the place of contact, and by examining the light transmitted through the prism. But as two prisms are required for this experiment, we may exhibit the colours by a much simpler apparatus, and also in a much more brilliant manner. Having taken a slip of thick crown glass, make a notch in its side with a file, and having applied to the notch a heated iron, it will speedily crack through a short space. This crack may be extended at pleasure by a re-application of the heated iron. If we now examine the surface of this crack at an angle less than that which gives total reflexion, we shall see the surface of the crack covered with coloured fringes parallel to the termination of the crack on the line of junction of the separated faces. These colours will be unusually brilliant, on account of the perfect polish of the separated surfaces. If the upper and under surfaces of the glass parallel to the crack are polished, the rays seen by transmission will also be observed with peculiar distinctness; and by the force of the hand either in opening or closing the crack, the breadth and position of the coloured fringes may be made to vary at pleasure.[*]

In order to study the phenomena of the coloured rings produced by thin plates, the method of exhibiting them in Fig. 1. should be adopted. Two convex lenses AB, CD, of very long foci, are placed the one above the other, so as to touch at their vertices. Three pair of clamp screws *p*, *p*, *p*, are then employed to keep the lenses together, and to increase the pressure in a regular and equal manner at the point of contact. Sir Isaac Newton used two object glasses, the one a plano-convex for a fourteen foot telescope, and the other a double convex for a fifty foot one. The first was laid with its plane side downwards like CD, and the other laid above it as AB. By pressing these lenses slowly together, so that the colours emerged successively in the middle of the circles, a circular system of coloured rings were displayed in the centre. The nature of these rings is thus described by Newton.

"Next to the pellucid central spot made by the contact of the glasses, succeeded *blue*, *white*, *yellow* and *red*. The *blue* was so little in quantity that I could not discern it in the circles made by the prisms, nor could I well distinguish any *violet* in it, but the *yellow* and *red* were pretty copious, and seemed about as much in extent as the *white*, and four or five times more than the *blue*. The next circuit in order of colours immediately encompassing these were *violet*, *blue*, *green*, *yellow*, and *red*: and these were all of them copious and vivid, excepting the *green*, which was very little in quantity, and seemed much more faint than the other colours. Of the other four, the *violet* was the *least* in extent, and the *blue less* than the *yellow* or *red*. The third circuit or order was *purple*, *blue*, *green*, *yellow*, and *red*; in which the *purple* seemed more reddish than the violet in the former circuit, and the green was much more conspicuous.—After this succeeded the fourth circuit of *green* and *red*. The green was very copious and lively, inclining on the one side to blue, and on the other side to yellow. But in this fourth circuit there was neither violet, blue, nor yellow, and the red was very imperfect. Also the succeeding colours became more and more imperfect and dilute, till after three or four revolutions they ended in perfect whiteness. Their form, when the glasses were most compressed so as to make the black spot appear in the centre, is delineated in the second figure; where *a*, *b*, *c*, *d*, *e* : *f*, *g*, *h*, *i*, *k* : *l*, *m*, *n*, *o*, *p* : *q*, *r* : *s*, *t* : *v*, *x* : *y*, *z*, denote the colours reckoned in order from the centre, *black*, *blue*, *white*, *yellow*, *red* ;—*violet*, *blue*, *green*, *yellow*, *red* ;—*purple*, *blue*, *green*, *yellow*, *red* ;—*green*, *red* ;—*greenish blue*, *red* ;—*greenish blue*, *pale red* ;—*greenish blue*, *reddish white*.

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[*] *Phil. Trans.* 1816, p. 73.

To determine the interval of the glasses, or thickness of the interjacent air, by which each colour was produced, I measured the diameters of the first six rings at the most lucid part of their orbits, and squaring them, found their squares to be in the arithmetical progression of the odd numbers, 1, 3, 5, 7, 9, 11, &c. And since one of these glasses was plane, and the other spherical, their intervals at those rings must be in the same progression. I measured also the diameters of the dark or faint rings between the more lucid colours, and found their squares to be in the arithmetical progression of the even numbers, 2, 4, 6, 8, 10, 12, &c."

Newton then proceeded to determine the thickness of the plate of air by which these different rings were produced. In order to do this, he measured the diameter of the fifth dark ring, as produced by two separate object glasses, the diameters of the spheres of which they formed a part being respectively 182 inches, and 184 inches, and he found it to be $\frac{100}{1774784}$ parts of an inch with the former, and $\frac{5}{88850}$ parts of an inch with the latter; and dividing each of these numbers by *five*, to get the diameter of the first ring, the intervals were $\frac{1}{88739}$, and $\frac{1}{88850}$. But as the rings were measured at an inclination of about four degrees with the perpendicular, the diameter of the rings must be diminished in the ratio of the radius to the secant of four degrees, that is, of 10000 to 10029, so that they become $\frac{1}{88952}$, and $\frac{1}{89063}$, the mean of which is nearly $\frac{1}{89000}$ part of an inch, *which is the thickness of the air at the darkest part of the first dark ring made by perpendicular rays.*

If we now multiply this number by the progression 1, 3, 5, 7, 9, &c. and by 2, 4, 6, 8, 10, &c. we shall have the following results :

	Thickness of Air at the most Luminous Point.	Thickness of Air at the most Obscure Point.
FIRST RING .	$\frac{1}{178000}$.	$\frac{2}{178000}$, or $\frac{1}{89000}$.
SECOND RING	$\frac{3}{178000}$.	$\frac{4}{178000}$.
THIRD RING .	$\frac{5}{178000}$.	$\frac{6}{178000}$.
FOURTH RING .	$\frac{7}{178000}$.	$\frac{8}{178000}$.

Sir Isaac next proceeded to measure the diameters of the rings at different obliquities, and he obtained the results in the following Table.

Angle of Incidence on the Air.		Angle of Refraction into the Air.		Diameter of the Ring.	Thickness of the Air.
Degr.	Min.				
00	00	00	00	10	10
06	26	10	00	$10\frac{1}{13}$	$10\frac{2}{13}$
12	45	20	00	$10\frac{1}{3}$	$10\frac{2}{3}$
18	49	30	00	$10\frac{3}{4}$	$11\frac{1}{2}$
24	30	40	00	$11\frac{2}{5}$	13
29	37	50	00	$12\frac{1}{2}$	$15\frac{1}{2}$
33	58	60	00	14	20
35	47	65	00	$15\frac{1}{4}$	$23\frac{1}{4}$
37	19	70	00	$16\frac{4}{5}$	$28\frac{1}{4}$
38	33	75	00	$19\frac{1}{4}$	37
39	27	80	00	$22\frac{6}{9}$	$52\frac{1}{4}$
40	00	85	00	29	$84\frac{1}{13}$
40	11	90	00	35	$122\frac{1}{2}$

From the measures contained in this table, Newton deduced the following rule : "That the thickness of the air is proportional to the secant of an angle, whose sine is a certain mean proportional between the sines of incidence and refraction. And that mean proportional, so far as, by these measures, I can determine it, is the first of an hundred and six arithmetical mean proportionals between those sines counted from the bigger sine, that is, from the sine of refraction when the refraction is made out of the glass into the plate of air, or from the sine of incidence when the refraction is made out of the plate of air into the glass."

Having thus described the rings seen by reflexion, Newton proceeds to those which are formed by transmission, and which appear by looking *through* the two object glasses. In this case the central spot was *white*, and from it the order of the colours were *yellowish red* ;—*black*, *violet*, *blue*, *white*, *yellow red* ;—*violet*, *blue*, *green*, *yellow*, *red*. These colours were however very faint, unless when the light was transmitted with much obliquity. The relation of the *reflected* to the *transmitted* rays, is shown in Fig. 3. where AB CD, are the surfaces of the glasses, touching one another at E, and the lines which join them represent their distances in arithmetical progression. The names of the colours engraved above, are those seen by reflected light, while those seen by transmitted light are engraven below.

When water was admitted between the lenses, the colours became fainter and the rings less; and upon measuring the intervals in water at which the same rings were produced, they were nearly to one another as the sines which measure the refraction out of that medium into air, viz. as about three to four in the case of water.

Sir Isaac next examined the phenomena of the rings when they were produced by the homogeneous light of the different colours of the spectrum. He found the *circles* formed in *red* light to be *larger* than those made in violet light, and he remarks, "that it was very pleasant to see them gradually swell or contract, according as the colour of the light was changed." The intervals of the glasses, when the same ray was formed in *red* and *violet* light, were as $14\frac{1}{2}$ to 9, if they were formed by the least or the most refrangible rays. From more detailed observations, Sir Isaac concluded that the thicknesses of the air between the glasses, where the rings were successively formed by the limits of the seven colours, *red*, *orange*, *yellow*, *green*, *blue*, *indigo*, and *violet*, are to one another as the cube roots of the square of the eight lengths of a chord, which sound the notes in an eighth, *sol*, *la*, *fa*, *sol*, *la*, *mi*, *fa*, *sol*, or *as the cube roots of the squares of the numbers* 1, $\frac{8}{9}$, $\frac{5}{6}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{9}{16}$, $\frac{1}{2}$, or 1; 0.924; 0.885; 0.825; 0.763; 0.711; 0 681; 0.630; that is, if 1 represent the interior diameter of any red ring, formed by the extreme red rays, the cube root of $\frac{8}{9}$ will express the interior diameter of a ring at the boundary of the *red* and *orange*, and so on for the limits of all the other coloured spaces.

M. Le Blanc has observed, that if the two extreme terms of the preceding numbers are multipled together, as $1 \times \frac{1}{2}$; or any other two at equal distances from the extremes, as $\frac{8}{9} \times \frac{9}{16}$, or $\frac{5}{6} \times \frac{3}{5}$, we shall obtain a product always equal to $\frac{1}{2}$. Hence if we suppose the colours of the spectra to be arranged in a circle, as shown in the article Accidental Colours, and Plate IV. Fig. 4. we shall obtain the following proportions of the coloured spaces, which differ very little from those formerly given by Newton.*

	Spaces deduced from the above Numbers.	Spaces given by Newton.	Difference.
Red	61°10′23	60°45′ 35″	24′ 49″+
Orange	33 31 10	34 10 38	39 28 —
Yellow	54 43 15	54 41 1	2 14 +
Green	61 10 23	60 45 34	24 49 +
Blue	54 43 15	54 41 1	2 14 +
Indigo	33 31 10	34 10 38	39 28 —
Violet	61 10 23	60 45 34	24 49 +

The sum of the *positive* and the *negative* differences is the same, viz. 1° 18′ 55″.

Sir Isaac next proceeds to detail his experiments on the rings produced by a denser medium, placed in a rarer one, or by bubbles of soapy water, plates of mica, or other thin substances, terminated on all sides with air.

In examining the soap bubbles Sir Isaac covered them, as soon as they were blown, with a clear glass, and in that way he saw the colours emerge like so many concentric rings, encompassing the top of the bubbles. As the bubble grew thinner by the subsidence of the water, the rays slowly expanded till they covered the whole bubble, descending regularly to the bottom of it, where they diminished in succession. After all the colours had emerged at the top, there arose in the centre of the rings a small round black spot, which dilated itself till it became sometimes more than $\frac{1}{2}$ or $\frac{3}{4}$ths of an inch broad before the bubble broke. Some smaller black spots appeared within it, but they were not altogether deprived of light; for the image of a candle or of the sun could be seen by reflexion, both from the small and the large ones.

By observing how much the colours at the same place of the bubbles were varied by the obliquities of the rays, Sir Isaac determined the thickness of the water which exhibited the same colour at different obliquities, to be nearly in the proportions given in the following table, the ratio of refraction being as 3 to 4.

Angle of Incidence in the Water.	Angle of Refraction in the Water.	Thickness of the Water.
0° 0′	0° 0′	10
15 0	11 11	$10\frac{1}{4}$
30 0	22 1	$10\frac{4}{5}$
45 0	32 2	$11\frac{4}{5}$
60 0	40 30	13
75 0	46 25	$14\frac{1}{2}$
90 0	48 35	$15\frac{1}{5}$

These results agree perfectly with the rule formerly deduced for thin plates of air. See page 693, col. 1.

In order to show how the colours of thin plates are composed, Sir Isaac Newton takes in any straight line YH, the distances YA, YB, YC, &c. as the numbers 6300, 6814, 7114, 7631, 8255, 8855, 9243, and 100000. (See p. 693, col. 1.) and at the points A, B, C, D, &c. he raises perpendiculars A α and B β, so that the intervals between them will represent the extent of the several colours written underneath them. The line A α, is then divided as the numbers 1, 2, 3;—5, 6, 7;—9, 10, 11;—13, 14, 15, &c. and through these divisions are drawn from Y, the lines 1 I, 2 K, 3 L, &c.

"Now, if A 2 be supposed to represent the thickness of any thin transparent body, at which the outermost *violet* is most copiously reflected in the first ring, then HK will represent its thickness, at which the outermost red is most copiously reflected in the same series. Also A 6 and HN will denote the thicknesses at which those extreme colours are most copiously reflected in the second series, and A 10 and HQ the thicknesses at which they are most copiously reflected in the third series, and so on. And the thickness at which any of the intermediate colours are reflected most copiously, will be defined by the distance of the line AH from the intermediate parts of the lines 2 K, 6 N, 10 Q, &c. against which the names of those colours are written below.

But, farther to define the latitude of these colours in each ring or series, let A 1 be the least thickness, and A 3 the greatest thickness, at which the extreme violet in the first series is reflected, and let HI, and HL, be the like limits for the extreme red, and let the intermediate colours be limited by the intermediate parts of the lines 1 I and 3 L, against which the names of those colours are written, and so on. But yet with this caution, that the reflexions be supposed strongest at the intermediate spaces, 2 K, 6 N, 10 Q, &c. and from thence to decrease gradually towards these limits, 1 I, 3 L, 5 M, 7 O, &c. on either side; where you must not conceive them to be precisely limited, but to decay indefinitely. And whereas I have assigned the same latitude to every series, I did it, because, although the colours in the first series seem to be a little broader than the rest, by reason of a stronger reflexion there, yet that inequality is so insensible as scarcely to be determined by observation.

Now, according to this description, conceiving that the rays, originally of several colours, are by turns reflected at the spaces 1 I L 3, 5 M O 7, 9 P R 11, &c. and transmitted at the spaces AHI 1, 3 LM 5, 7 OP 9, &c. it is easy to know what colour must in the open air be exhibited at any thickness of a transparent thin body. For if a ruler be applied parallel to AH, at that distance from it by which the thickness of the body is represented, the alternate spaces 1 IL 3, 5 MO 7, &c. which it crosseth, will denote the reflected original colours, of which the colour exhibited in the open air is compounded. Thus, if the constitution of the green in the third series of colours be desired, apply the ruler as you see at $\pi \rho \sigma \phi$, and by its passing through some of the blue at π, and yellow at σ, as well as through the green at ρ, you may conclude that the green exhibited at that thickness of the body is principally constituted of original green, but not without a mixture of some blue and yellow.

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* See Biot's *Précis Elementoire de Physique*, tom. ii. p. 443, note.

By this means you may know how the colours, from the centre of the outward rings ought to succeed in order as they were described. For, if you move the ruler gradually from AH through all distances, having past over the first space which denotes little or no reflexion to be made by the thinnest substances, it will first arrive at 1 the violet, and then very quickly at the blue and green, which, together with that violet compound blue, and then at the yellow and red, by whose farther addition that blue is converted into whiteness, which whiteness continues during the transit of the edge of the ruler from I to 3, and after that by the successive deficiency of its component colours. turns first to compound yellow, and then to red, and last of all the red ceaseth at L. Then begin the colours of the second series, which succeed in order during the transit of the edge of the ruler from 5 to O, and are more lively than before, because more expanded and severed. And for the same reason, instead of the former white there intercedes between the blue and yellow a mixture of orange, yellow, green, blue, and indigo, all which together ought to exhibit a dilute and imperfect green. So the colours of the third series all succeed in order; first, the violet, which a little interferes with the red of the second order, and is thereby inclined to a reddish purple; then the blue and green, which are less mixed with other colours, and consequently more lively than before, especially the green: Then follows the yellow, some of which towards the green is distinct and good, but that part of it towards the succeeding red, as also that red, is mixed with the violet and blue of the fourth series, whereby various degrees of red, very much inclining to purple, are compounded. This violet and blue, which should succeed this red being mixed with, and hidden in it, there succeeds a green. And this at first is much inclined to blue, but soon becomes a good green, the only unmixed and lively colour in this fourth series. For as it verges towards the yellow, it begins to interfere with the colours of the fifth series, by whose mixture the succeeding yellow and red are very much diluted and made dirty, especially the yellow, which, being the weaker colour, is scarce able to show itself. After this the several series interfere more and more, and their colours become more and more intermixed, till, after three or four more revolutions, (in which the red and blue predominate by turns) all sorts of colours are in all places pretty equally blended, and compound an even whiteness.

And since the rays endued with one colour are transmitted where those of another colour are reflected, the reason of the colours made by the transmitted light is from hence evident.

If not only the order and species of these colours, but also the precise thickness of the plate, or thin body at which they are exhibited, be desired in parts of an inch, that may be also obtained by the assistance of the preceding observations. For, according to those observations, the thickness of the thinned air, which between two glasses exhibited the most luminous parts of the first six rings, were $\frac{1}{178000}$, $\frac{3}{178000}$, $\frac{5}{178000}$, $\frac{7}{178000}$, $\frac{9}{178000}$, $\frac{11}{178000}$, parts of an inch. Suppose the light reflected most copiously at these thicknesses be the bright citrine yellow, or confine of yellow and orange, and these thicknesses will be $F\lambda$, $F\mu$, $F\xi$, $F o$, $F\tau$. And this being known, it is easy to determine what thickness of air is represented by $G\phi$, or by any other distance of the ruler from AH.

But, farther, since the thickness of air was to the thickness of water, which between the same classes exhibited the same colour, as 4 to 3, and the colours of thin bodies are not varied by varying the ambient medium; the thickness of a bubble of water, exhibiting any colour, will be ¾ of the thickness of air producing the same colour. And so, according to the same observations, the thickness of a plate of glass, whose refraction of the mean refrangible ray is measured by the proportion of the sines 31 to 20, may be $\frac{20}{31}$ of the thickness of air producing the same colours; and the like of other mediums. I do not affirm that this proportion of 20 to 31, holds in all the rays; for the sines of other sorts of rays have other proportions. But the differences of those proportions are so little that I do not here consider them. On these grounds I have composed the following table, wherein the thickness of air, water, and glass, at which each colour is most intense and specific, is expressed in parts of an inch divided into ten hundred thousand equal parts.

The Thickness of Coloured Plates and Particles of Air, Water, *and* Glass.

	Reflected Tints.	Transmitted Tints.	Air.	Water	Glass
Their colours of the FIRST order,	Very black		$\frac{1}{2}$	$\frac{3}{8}$	$\frac{10}{31}$
	Black	White	1	$\frac{3}{4}$	$\frac{20}{31}$
	Beginning of black		2	$1\frac{1}{2}$	$1\frac{2}{7}$
	Blue	Yellowish red	$2\frac{2}{5}$	$1\frac{4}{5}$	$1\frac{11}{22}$
	White	Black	$5\frac{1}{4}$	$3\frac{7}{8}$	$3\frac{2}{5}$
	Yellow	Violet	$7\frac{1}{9}$	$5\frac{1}{3}$	$4\frac{3}{5}$
	Orange		8	6	$4\frac{1}{6}$
	Red	Blue	9	$6\frac{3}{4}$	$5\frac{4}{5}$
Of the SECOND order	Violet	White	$11\frac{1}{6}$	$3\frac{3}{8}$	$7\frac{1}{5}$
	Indigo		$12\frac{5}{6}$	$9\frac{5}{8}$	$8\frac{2}{11}$
	Blue	Yellow	14	$10\frac{1}{2}$	9
	Green	Red	$15\frac{1}{8}$	$11\frac{1}{3}$	$9\frac{5}{7}$
	Yellow	Violet	$16\frac{2}{7}$	$12\frac{1}{5}$	$10\frac{2}{5}$
	Orange		$17\frac{2}{9}$	13	$11\frac{1}{9}$
	Bright red	Blue	$18\frac{1}{5}$	$13\frac{3}{4}$	$11\frac{5}{6}$
	Scarlet		$19\frac{2}{3}$	$14\frac{3}{4}$	$12\frac{2}{3}$
Of the THIRD order,	Purple	Green	21	$15\frac{3}{4}$	$13\frac{11}{20}$
	Indigo		$22\frac{1}{10}$	$16\frac{4}{7}$	$14\frac{1}{4}$
	Blue	Yellow	$23\frac{2}{5}$	$17\frac{11}{20}$	$15\frac{1}{10}$
	Green	Red	$25\frac{1}{6}$	$18\frac{6}{10}$	$16\frac{1}{4}$
	Yellow		$27\frac{1}{7}$	$30\frac{1}{3}$	$17\frac{1}{2}$
	Red	Bluish green	29	$21\frac{3}{4}$	$18\frac{5}{7}$
	Bluish red		32	24	$20\frac{2}{3}$
Of the FOURTH order,	Bluish green		24	$25\frac{1}{2}$	22
	Green	Red	$35\frac{2}{7}$	$26\frac{1}{2}$	$22\frac{3}{4}$
	Yellowish green		36	27	$23\frac{2}{9}$
	Red	Bluish green	$40\frac{1}{3}$	$30\frac{1}{4}$	26
Of the FIFTH order	Greenish blue	Red	46	$34\frac{1}{2}$	$29\frac{2}{3}$
	Red		$52\frac{1}{2}$	$39\frac{3}{8}$	34
Of the SIXTH order,	Greenish blue		$58\frac{3}{4}$	44	38
	Red		65	$48\frac{3}{4}$	42
Of the SEVENTH order	Greenish blue		71	$53\frac{1}{4}$	$45\frac{4}{5}$
	Ruddy white		71	$57\frac{3}{4}$	$49\frac{2}{3}$

This table, which is of very extensive use, will be afterwards repeatedly referred to, under the name of *Newton's Table*, or *scale of Colours*. See Newton's *Optics*, b. ii. part i. and ii. Dr. Young's *Nat. Phil.* vol. i. and ii. Biot's *Traité de Physique*, tom. iv.; and Dr. Herschel, in *Phil Trans.* 1807, part ii.

Sect. II.—*On the Theory of the Colours of Thin Plates, or the Theory of Fits of Easy Reflexion and Transmission.*

In order to represent the various phenomena described in the preceding section, Sir Isaac Newton devised the theory of Fits of Easy reflexion and Transmission, which may be considered as a general method of expressing all the various facts which he observed, and which may be adopted, whether we adopt the theory of emission or undulation. As our limits will not permit us to detail Sir Isaac Newton's views on this subject, we shall content ourselves with the enumeration of the propositions which constitute the theory, all of which are directly deducible from the phenomena of thin plates, described in the preceding section.

"1. Every ray of light, in its passage through any refracting surface, is put into a certain transient constitution, or state, which in the progress of the ray returns at equal intervals, and disposes the ray at every return to be easily transmitted through the next refracting surface, and, between the returns, to be easily reflected by it.

Definition.—The returns of the disposition of any ray to be reflected, I will call its *Fits of easy reflexion*; and those of its disposition to be transmitted, its *Fits of easy transmission*; and the space it passes between every return and the next return, the *Interval of its Fits*.

2. The reason why the surfaces of all thick transparent bodies reflect part of the light incident on them, and refract the rest, is, that some rays at their incidence are in Fits of easy reflexion, and others in Fits of easy transmission.

3. Those surfaces of transparent bodies, which, if the ray be in a Fit of refraction, do refract it most strongly, if the ray be in a Fit of reflexion, do reflect it most easily.

4. In any one and the same sort of rays emerging in any angle out of any refracting surface into one and the same medium, the interval of the following fits of easy reflexion and transmission are either accurately, or very nearly, as the rectangle of the secant of the angle of refraction, and of the secant of another angle, whose sine is the first of 106 arithmetical mean proportionals, between the sines of incidence and refraction counted from the sine of refraction.

5. In several sorts of rays emerging in equal angles out of any refracting surface into the same medium, the intervals of the following fits of easy reflexion and easy transmission are either accurately, or very nearly; as the cube roots of the squares of the lengths of a cord, which sound the notes in an eighth, *sol, la, fa, sol, la, mi, fa, sol*, with all their intermediate degrees answering to the colours of these rays, according to the analogy described in Prop VI. p 667.

6. If rays of any one sort pass perpendicularly into several mediums, the intervals of the fits of easy reflexion and transmission in any one medium, are to those intervals in any other as the sine of incidence is to the sine of refraction, when the rays pass out of the first of those two mediums into the second.

7. If the rays which paint the colour in the confine of yellow and orange, pass perpendicularly out of any medium into air, the intervals of their fits of easy reflexion are the $\frac{1}{89000}$th part of an inch. And of the same length are the intervals of their fits of easy transmission.

8. If any sort of rays falling on the polished surface of any pellucid medium be reflected back, the fits of easy reflexion which they have at the point of reflexion, shall still continue to return, and the returns shall be at distances from the point of reflexion in the arithmetical progression of the numbers 2, 4 6, 8, 10, 12, &c. and between these fits the rays shall be in fits of easy transmission.

9. The intervals of the fits of easy reflexion and easy transmission, propagated from points of reflexion into any medium, are equal to the intervals of the like fits which the same rays would have, if refracted into the same medium in angles of refraction equal to their angles of reflexion."

On the hypothesis of undulations, the colours of thin plates are supposed to arise from the interference of the light reflected from the second surface of the plate with the light reflected from the first surface. Thus in Fig. 5. if rays of light RA, RC, fall on a rarer medium MN, the ray RA, refracted at A, and reflected again at E, will interfere with the ray RC, reflected at C. Drawing AB, CD, perpendicular to the rays RC, RA, the time of passing through BC and AD will be equal, and DE will be half the interval of retardation, and will be to CE as Sin. DCE : Rad. Hence, in order that the same colour may be reflected, or that DE may be constant, the thickness CE must vary as the secant of the angle of refraction CED, which agrees exactly with Newton's experiments. See Dr. Young's *Lect. on Nat. Phil.* vol. ii. p. 626; and Hooke's *Micrographia*, p. 65. 67.

SECT. III.—*On the Colours of Thick Plates.*

The phenomena of the colours of thick plates, or mirrors, were discovered by Sir Isaac Newton, and are described very fully in the *Fourth* Part of the *Second* Book of his *Optics*. The light of the sun RR, Fig. 6. being admitted through the window shutter by a small aperture, one-third of an inch in diameter, Sir Isaac received it on a glass speculum M, ground concave on the anterior side, and convex on the posterior side, to a sphere of 5 feet 11 inches radius, and quicksilvered on the convex side. He then held a sheet of white paper AB, 5 feet 11 inches in front of it, at the centre of its surfaces, and observed on the paper *four* or *five* concentric rings of colours surrounding the central spot, and resembling the rings *transmitted* through thin plates. When the ray RR was *red* homogeneous light, the rings were all *red*, and so on with the other homogeneous colours; their diameters being *largest* in the *red*, and *least* in the *violet*. The squares of the diameters of the *most luminous* parts in the same homogeneous light were in the arithmetical progression 0, 1, 2, 3, 4, &c. and the squares of the diameters of the *darkest* parts were as the intermediate numbers $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$. Sir Isaac also found that the same rings were produced when the quicksilver was rubbed off the concave mirror, with the difference only of their being much fainter, and he found that they were not produced by a metallic speculum.

Upon substituting another glass mirror, whose thickness was five-sixths of an inch, that of the first being one-fourth of an inch, Sir Isaac found that the formation of these rings depended on both the surfaces of the glass, and that, *ceteris paribus*, the diameters of the rings were reciprocally as the square roots of the thickness of the mirror. He found, likewise, that the rings now described were produced by the faint light reflected or scattered irregularly; for, as he remarks, however well any glass or speculum may be polished, its polished surface, when illuminated in a dark room by a beam of the sun's light, may be easily seen in all positions of the eye.

All the phenomena of thick plates are capable of being explained by the hypothesis of fits of easy reflexion and transmission, while in the undulatory system they are ascribed to the interference of two portions of light, the one dissipated or scattered by the anterior surface of the mirror of glass before reflexion, and the other dissipated by the same surface, when the ray is on its return after reflexion.

The Duke de Chaulnes found that analogous effects were produced when the light was transmitted through a screen of gauze or muslin, or through a semi-transparent substance before it, and was afterwards reflected from a metallic speculum; but in all these cases, when the mirror is metallic, the gauze, or the screen, or the transparent film, must be at some small distance in front of the mirror.

The effect of the irregular dissipation of the light is well shown in Sir William Herschel's experiment of scattering a fine white powder in a beam of light reflected perpendicularly by a concave mirror, which exhibits the coloured rings when received on a screen in its return; or an analogous effect may be produced by scattering powder on the face of the common looking-glass. For farther information on this subject, see Newton's *Optics*, book ii. part iv.; Dutour, in Rozier's *Journal*, i. 368. ii. 11. 349. v. 120. 230. and vii. 330. 341; De Chaulnes, *Mem. Acad. Par.* 1705, p. 136; Sir W. Herschel, *Phil. Trans.* 1807, Part II.; and Biot's *Traité de Physique*, tom. iv. p. 149, where this subject is treated in very great detail.

SECT. IV.—*On the Colours produced by successive Reflexions from Double Plates of Equal Thickness.*

The phenomena which we propose to describe shortly in this section, were discovered by Dr. Brewster, in the course of a series of experiments on the polarisation of light by successive reflexions from plates of glass. The plates which he used, were two plates of parallel glass, formed out of the same piece, and therefore having rigorously the same thickness.

In order to observe the phenomena to the greatest advantage, let the light of a circular image, subtending an angle of 1° or 2°, be incident perpendicularly, or nearly so, upon two plates of parallel glass, placed at the distance of one-tenth of an inch, and let one of the plates be gently inclined to the other, till one or more of the reflected images be distinctly separated from the bright image formed by transmitted light, and received upon the eye, placed behind the plates. Under these circumstances, the reflected image will be crossed with about fifteen or sixteen beautiful parallel fringes. The three central fringes consist of blackish and whitish stripes, and the exterior ones of brilliant stripes of red and green light; and the central fringes have the same appearance in relation to the external fringes, as the internal have to the external rings, formed either by thin plates, or by the action of topaz upon polarised light. If the two plates of glass are turned round in a plane at right angles to the incident ray, the reflected images will move round the bright image, and the parallel fringes will always preserve a direction at right angles to a line joining the centres of the bright and reflected images. Hence it follows, *that the direction of the fringes is always parallel to the common section of the four reflecting surfaces, which exercise an action upon the incident light.*

The position of the plates remaining as before, let the inclination of the plates, or, what is the same thing, the distance of the bright and the reflected image, be varied by a gentle motion of one of the plates, the coloured fringes will be found to increase in breadth as the inclination of the plates is diminished, and to diminish as the inclination of the plates is increased.

If the light of the circular object, instead of falling perpendicularly upon the plates, is incident at different obliquities, so that the plane of incidence is *at right angles to the common section of the plates*, no fringes are visible across any of the images. But if the plane of incidence is *parallel to the common section of the plates*, the reflected images increase in brightness with the obliquity of incidence, and the coloured fringes become more vivid. When the angle of incidence increases from 0° to 90°, the images that have suffered the greatest number of reflexions are crossed by other fringes, inclined to them at a small angle. At an angle of about 44°, the image formed by four reflexions is covered with interfering fringes; but it is not till the angle of incidence is greater, that this is distinctly seen on the image formed by two reflexions.

Hitherto he had observed no fringes upon the first or bright image, which is obviously composed of light that has not suffered reflexion from the second plate of glass. By concealing, however, the bright light of the first image, so as to perceive the image formed by a second reflexion, within the first plate, and by viewing this image through a small aperture, which he found of the greatest service in giving distinctness to all the phenomena, he observed fringes across the first image, far surpassing in precision of outline, and in richness of colouring, every analogous phenomenon which he had seen. When these fringes were concealed, he also observed other fringes on the image immediately behind them, and formed by a third reflexion, from the interior of the first plate. He now concealed the second image, upon which the fringes were extremely bright, and very faint stripes were seen upon the one immediately behind it.

In examining these phenomena a little more attentively, he observed that the size of the fringes in the first image varied with the distance of the eye from the plates, while those on the second and fourth image diminished with that distance.

In pursuing this inquiry, Dr. Brewster found *that the production of the fringes depends upon the action of all the four surfaces of the two plates of parallel glass; and that the magnitudes of the fringes are inversely as the plates that produce them at a given inclination.*

When the eye is placed between the plates and the luminous object, so as to see the first, third, fifth, seventh, &c. reflected images, the coloured fringes are also seen, and have the same character as those already described.

All these phenomena are seen when polarised light is used in place of common light.

In order to explain the changes which the light undergoes in its passage through the plates of glass, let AB, CD, Fig. 7. be a section of two plates at right angles to the common section of their surfaces, and let RS be a ray of light incident nearly in a vertical direction. This ray, after passing through the first plate AB, will suffer a small refraction at P and Q, and emerge in the direction QV parallel to RS. At the point P, in the second plate CD, the ray TP will be reflected to *a*, again reflected to *b*, and, after suffering a refraction at *b* and *c*, will emerge in the direction *c d*, forming with RV an angle equal to twice the inclination of the plates. A portion of the reflected ray P *a*, will enter the first plate at α, and having suffered reflexion and refraction at β, the reflected portion $\beta\ \gamma$ will reach the eye at θ. The ray P *a b c* will likewise suffer a reflexion at *c* and *c*, and will reach the eye at *g*. In like manner, a part of the ray PQ will be reflected at Q, and move in the direction Q *r s t u v*, and another part of it in the direction *s w x y z*, and these rays will suffer several other reflexions; but the images which they form will be so faint, that the eye will not be capable of perceiving them. When the observer, therefore, looks at a luminous body, in the direction SR, through the glass plates, he will perceive two images, one of which is a bright image, seen by the transmitted light QV, and the other is a faint image, seen principally by the reflected light P *a b c d*, and composed of several images, formed by the pencils *c d*, *u v*, $\epsilon\ \theta$, *z &*, and *e g*. The bright image is not crossed by coloured fringes, but the fringes appear distinctly upon the other image; and the light by which these fringes are formed, has suffered two reflexions from the exterior surfaces, and two refractions at the interior surfaces of the plates.

In explaining the preceding facts by his law of interference, Dr. Young remarks, " that the effect of the inclination of the plates in these experiments, is to reduce the virtual thickness of the plate in the ratio of the cosine; and the difference of the cosines of equidistant arcs being simply as the sine of their half sum, it is evident that the colours must correspond to a thickness which varies nearly as the sine of the angle of incidence, considered with regard to a plane bisecting the angle formed by the plates; and this result agrees correctly with Dr. Brewster's experiments." For a farther account of these experiments, see the *Edinburgh Transactions*, vol. vii. p. 435; and Biot's *Traité de Phisique*, tom. iv. p. 246.

SECT. V.—*On the Colours of Double Plates of unequal Thickness.*

When two plates differ very little in thickness, light transmitted through them will exhibit the same colours as a single plate, whose thickness is equal to their difference, whatever be the distance of the two plates. Mr. Nicholson first observed colours of this kind in the glasses employed for the sights of sextants, and he considered them as analogous to those of thin plates. Dr. Young, however, attributed them to a slight difference in the thickness of the glasses, the rays twice reflected within the first glass only, interfering with the rays twice reflected in the second.

A series of very interesting but analogous phenomena have been lately observed by Mr. Knox of Belfast. Having formed the Newtonian rings by placing a convex surface of glass upon a piece of good looking-glass plate, he observed the primary rings formed by reflexion from the plate of air, and also the transmitted rings reflected to his eye by the mirror-glass. In this way he saw at once the reflected and transmitted rings, as shown at AB, Fig. 8.; but he was surprised to perceive between them the system of parallel fringes CDFE, passing through the intersections of the two circular systems A and B. These parallel fringes were equal in number to the rings of both the sets A and B taken together. They were equidistant, extended to the edge of the lens on both sides, and were formed at right angles to the direction of the light, and to a line joining the centres of the primary set of rings and its reflected image.

Mr. Knox now tried what would be the effect of combining in a similar manner two primary systems of rings. For this purpose he laid a double convex lens of about 36 inches focus on a flat piece of looking-glass, having its under side painted black, and on the lens he placed a piece of plain glass plate. In this way two sets of primary rings were produced, whose relative positions could be altered at pleasure. By using the shadow of a black card, he found that, instead of parallel fringes, as in Fig. 8. he had a new species of rings of a circular form, from two to three times the diameter of the primary rings from which they originated. These rings passed, as before, through the intersections of the primary one; and the ring which divided the two classes passed through a point, whose distances from the centre of each primary set were in proportion to their longest diameters.

These rings, which Mr. Knox calls *intersectionary* ones, may be made to vary infinitely in their demensions, according as the diameters of the primary sets differ more or less, being least where that difference is greatest, and increasing in size as the two primary sets approach to equality, until at last they become straight lines, when the two primary sets are equal. The dimensions of the intersectionary rings will also, as Mr. Knox remarks, *ceteris paribus*, diminish as the two primary sets approach, and increase as they recede from, one another.

As these intersectionary rings are almost always accompanied by a second, and sometimes by a third set of equal or unequal dimensions, Mr. Knox supposes that they may be produced by primary sets, combined with either transmitted or reflected sets, provided the two between which they are formed are of unequal dimensions.

Considering the intersectionary fringes as diagonals to the angles at which they were formed, Mr. Knox conjectured that if he could form rectilineal fringes by flat plates, and combine them at different angles, he would produce a third or diagonal set placed between the other two. He accordingly took a pair of slips of glass, and by applying two of their ends together, and using some friction, and a considerable degree of pressure, he formed a fine set of rectilineal fringes. By applying a third slip of glass longitudinally to the upper one of the first two, he formed a similar set of rectilineal fringes at right angles to the first; and he immediately observed the diagonal fringes, which he had anticipated, appear in the angle between the two primary sets, as shown in Fig. 9. where B and C are the primary fringes, and D the intersectionary set, divided into two classes, as shown by the dotted line. By forming the second set of fringes at different angles with the first, the central band of the intersectionary fringes always bisected the angle. It is a curious circumstance, that though the diagonal fringes are formed by the crossing of the two primary sets, yet they never appear at the opposite angle A, nor could they be made to appear in any angle formed by primary fringes, unless these fringes were so disposed as to have their red sides turned towards each other.

The phenomena observed by Mr. Knox may be explained, by considering the actual thicknesses of the plates of air by which they are formed. "In order that the thicknesses of plates of air contained between two unequal pairs of lenses may be equal, the distances from the centres of contact must be in a constant proportion; and it is well known, that all the points from which the lines drawn to two given points are in a constant proportion, will be found in the circumference of a circle, the diameter of which is a third proportional to the difference and sum of the segments of the given distance of the points; so that the colours depending on this difference, instead of beginning, as usual, from a white central spot, will begin from a white ring, and will be arranged in concentric rings on each side of it, precisely in the same order as when they form concentric rings round an actual point of contact; and when the curvatures of the two pairs of lenses are equal, the diameter of the circle becoming infinite, it will obviously be converted into a right line." *Sup. Encyc. Brit.* Art. CHROMATICS.

For farther information on the subject of this section, see Nicholson's *Journal*, vol. ii. p. 312. Dr. Young's *Lect. on Nat. Phil.* vol. ii. p. 317; and Mr. Knox's paper, in the *Phil. Trans.* 1815, p. 161.

SECT. VI.—*On the Colours of Mixed Plates.*

The colours of *mixed plates*, were discovered by Dr. Thomas Young, while looking at a candle through two pieces of plate glass with a little moisture between them. He observed the appearance of fringes, like the common colours of thin plates; and upon looking for the fringes by reflexion, he found that the new fringes were always in the same direction as the other fringes, but many times larger. These colours were always most distinctly seen when the glasses were placed a little out of the line, joining the eye and the luminous object. Upon examining the glasses with a magnifier, Dr. Young perceived that wherever these fringes were visible, the moisture was intermixed with portions of air, producing the appearance of dew. The same effect is produced by oil and air, and oil and water. By greasing partially a lens a little convex, and a flat glass, and holding them together between the eye and the termination of a bright object, Dr. Young observed the effect shown in Fig. 10. The effect is most conspicuous in the portion seen on the dark part beyond the object, being produced by the light scattered irregularly from the surface of the fluid. The effects, however, are here inverted, the one half of the series beginning from *black*, as in the common reflected rings of thin plates; and the other half beginning from *white*, as in the transmitted rings. The diameters of the rings vary with the refractive power of the fluid employed, diminishing as the refractive power increases, and increasing greatly in magnitude when two fluids, such as oil and water, differing little in refractive power, are employed.

In explaining the colours of mixed plates, Dr. Young supposes that they arise from the interference of two portions of light moving with different velocities, viz. the light transmitted through the *water*, and light transmitted through the *air*, or through the *oil*, when water and oil are mixed. In the case of water and air, whose ratios of refraction are as three to four, the fringes ought to appear when the thickness is six times as great as that which corresponds to the same colours in the case of thin plates; and Dr. Young actually found, that the sixth dark circle had the same diameter as the first circle in mixed plates. In order to understand the formation of these colours, Dr. Young supposes MN, Fig. 11. to be the glasses containing the transparent portions or drops, and that it is placed behind a dark object, such as A. Then the whole of the light which reaches the eye at O, to the right hand of PO, is either refracted through the edges of the drops, as at B, C, or reflected from the internal surface, as at D, E, while the light to the left hand of PO consists of rays refracted as before through the edges, as F, G, or simply passing through the fluid, as at H, I. The combinations of these portions of light will, therefore, exhibit series of colours in different orders, as the internal reflexion modifies the interference of the rays, on the side of the dark object, as in the colours of thin plates seen by reflexion. When the dark object at A is withdrawn, both these series of colours are produced at once; but being of an opposite nature, they neutralize each other, and produce white light.

In examining the dust of the *Lycoperdon bovista*, which he had placed in a glass with a drop of water, Dr. Young observed a *purple* tinge by reflected light, while the light transmitted through the water was of a *yellowish-green* colour. By substituting fluids of different densities in place of the water, the colours rose in the series, as if the plates were made thinner. Thus, when the water was saturated with *salt*, the *yellow-green* colour became nearly *blue*, and the *purple* more *red* or more brown. In *olive oil* the transmitted light was *purple*, and the oblique light *greenish*; while in *balsam of Tolu* the *purple* became *red*, and the incident light afforded a *faint blue*. In air, too, Dr. Young found that the powder became of a bright *blue green* colour by direct light, and of a *purplish* hue with a light a little oblique.

A series of colours, analogous to the preceding, have been observed by Dr. Brewster. He took some rich milk, and having laid it on a plate of glass MN, Fig. 12. in an uniform film, he examined the light transmitted through the fluid part *c d*, and through the part *b e*, that was in the act of drying, and separated the dried part *a b* from the fluid part *c d*. When a luminous body was examined through *c d*, its colour was *blue*, towards *c* it became *purple*, then *red*, *orange*, *yellow*, and, lastly, *white* at *b* and from *b* to *a*. The colours, therefore, *descend* in the scale from *c* to *b*, and consequently they cannot arise from the evaporation of the aqueous part of the fluid between *b* and *c*, by which its refractive power should increase from *c* to *b*; for in this case the colours would *rise* in the scale. Nor are these colours produced by the inclination of the surface *b c*; for when, in the process of drying upon a large surface, *c d* is parallel to MN, the red colour of the transmitted ray is very brilliant. The colours, therefore, are probably owing to a diminution of the particles of the milk during the process of evaporation.

For farther information on the subject of this section, see Dr. Young's *Lectures on Natural Philosophy*, vol. i. p. 787, Fig. 450; and vol. ii. p. 635. 680: and his *Introduction to Medical Literature*, p. 556.

SECT. VI.—*On the Colours of Fibres and Minute Particles.*

It has been long known, that a candle seen through a plate of glass covered with vapour, or with minute particles of dust, is encircled with a corona, or ring of colours. Blood, a little diluted, and the seed of the Lycopodium, exhibit these rings of colours in great perfection. When we look at a candle through these substances, we observe a light area, terminating in a *reddish* dark margin, then follows a ring of *bluish-green*, and without it a *red* ring; and when the particles or fibres are very uniform, the alternations of *green* and *red* are often repeated several times. Dr. Young observed, that the diameter of these rings increased as the particles or fibres which produced them were smaller, and that for the same particles they had always the same magnitude. He therefore conceived the ingenious idea of employing the diameter of the first ring, or of the limit of the first green ring and the red, as a measure of the diameters of the particles and fibres that produced it. In this way he constructed an instrument, which he called an *Eriometer*, by means of which the diameters of that ring could be measured in all bodies composed of particles and fibres. This Eriometer consists of a plate of brass, or piece of card, having a central aperture about one-thirtieth or one-fiftieth of an inch in diameter, surrounded by a circle of perforations about two-thirds or two-fifths of an inch in diameter; the number of perforations in each circle being eight or ten, and as minute as possible. When these dimensions are adopted, the eye requires the assistance of a lens. The substance to be examined is then fixed in some wires, which are carried by a slider, and the plates being held before an Argand lamp, or two or three candles placed in a line, the slider is drawn out till the coloured circle coincides with the circle of perforations, and the index then shows the number on the scale which indicates the magnitude of the fibres or the particles. Dr. Wollaston having found that the seed of the *Lycoperdon bovista*, or Puff-ball, was $\frac{1}{8500}$th of an inch in diameter, Dr. Young determined that the ring formed by it measured $3\frac{1}{2}$ on his eriometric scale, and hence he concluded, that the diameter of these seeds was $3\frac{1}{2} \times 8500 = 29750$. He therefore assumes $\frac{1}{30000}$, or one-*thirty thousandth* part of an inch, as the value of an unit in the eriometrical scale. The following are some of the principal results which Dr. Young obtained with his eriometer.

Substances measured by the Eriometer.

	Parts of the Eriometrical Scale.
Milk, diluted, very indistinct, about	3
Dust of *lycoperdon bovista*, very distinct	$3\frac{1}{2}$
Bullock's blood, from beef	$4\frac{1}{2}$
Smut of barley, called male ear	$6\frac{1}{3}$
Blood of a mouse	$6\frac{1}{2}$
Human blood diluted with water, 5; after standing some days, 6, or	7
Blood recently diluted with serum only	8
Pus	$7\frac{1}{2}$
Silk, very irregular, about	12
Beaver wool, very even, (jointed)	13
Angola wool, about	14
Vigonia wool	15
Siberian hare's wool, Scotch hare's wool, foreign coney wool, yellow rabbit's wool, about	$15\frac{1}{2}$
Mole's fur, about	16
Skate's blood, very indistinct, about	16
American rabbit's wool, British coney wool, about	$16\frac{1}{2}$
Buffalo's wool	18
Wool of the ovis montana	18
Finest seal wool, mixed, about	$18\frac{1}{2}$
Shawl wool 18, or	19
Goat's wool	19
Cotton, very unequal, about	19
Peruvian wool, mixed, the finest locks	20
A small lock of Welsh wool	20
Saxon wool, a few fibres 17, some 23, chiefly	22
An Escurial ram, at Lord Somerville's show, 23 to	24

	Parts of the Eriometrical Scale.
Mr. Western's South Down, some specimens	$24\frac{1}{2}$
Lioneza wool, 24 to 29, generally	25
Paular wool, 24 to 29, generally	$25\frac{1}{2}$
Alpacca wool, about	26
Farina of *laurestinus*	26
Ryeland Merino wool, Mr. Henty	27
Merino South Down wool, Mr. Henty	28
Seed of *lycopodium*, beautifully distinct	32
South Down ewe, Mr. W. B.	39
Coarse wool, Sussex	46
Coarse wool from some worsted	60

If we divide $\frac{1}{30000}$ by any of the numbers in the preceding table, we obtain the diameter of the fibre, or particle, in parts of an inch. Thus, milk being 3, we have $\frac{1}{30000} \div 3$, or $\frac{3}{30000}$, or $\frac{1}{40000}$th part of an inch for the diameter of the particle of milk.

Dr. Young has remarked, that it would not be difficult to obtain from these measures a tolerable approximation to the value of wool at its usual prices. If we square the number belonging to the kind of wool in the table, and subtract 325, the remainder will be nearly the number of pounds of the wool that are worth 100 guineas. Thus, for good Lioneza, whose number is 25, we shall have $25 \times 25 - 325 = 300$ lb. for 100 guineas, or 7s. per pound. See Dr. Young's *Introduction to Medical Literature*, p. 552.

SECT. VII.—*On the Colours of Mother of Pearl and Striated Surfaces.*

Mother-of-pearl is a well known substance, obtained principally from the shell of the pearl oyster; and from the facility with which it can be cut and polished, it has been long employed for a variety of useful and ornamental purposes. Every person must have observed the fine play of the prismatic colours to which mother-of-pearl owes its value as an ornamental substance, &c. and the ever-varying succession of fresh tints which may be developed, either by changing the inclination of the plate, or the direction of the light in which it is placed. The nature and origin of these colours have never been investigated: they have been carelessly ascribed to the laminated structure of the shell, and have been regarded as a fine proof of the Newtonian theory of the colours of natural bodies.

In order to observe all the properties which we propose to describe in this section, we must select a piece of regularly formed mother-of-pearl, which is known by the uniformity of its white colour in day-light, resembling somewhat the pearl itself, and scarcely exhibiting any of the prismatic tints. This regularity of structure is not often to be met with in the ordinary pieces of mother-of-pearl, nor is it indispensably necessary for the mere exhibition of some of its most remarkable properties; but, in order to understand the nature and origin of the colours, the experiments must be repeated with pieces that are regularly formed.

If we take a plate of regularly formed mother-of-pearl, having its two opposite surfaces ground perfectly flat, (but not polished,) either upon a blue stone, or upon a plate of glass, with the powder of schistus, and if, with the eye placed close to the plate, we view in it, by reflexion, a candle standing at the distance of a few feet, we shall observe a dull and imperfect image, free from all prismatic colours. This image is formed upon the ordinary principles of reflexion, and is faint and undefined, owing to the imperfect reflecting power of the ground surface. On one side of this imperfect image will be seen a brighter image, glowing with the prismatic colours, and separated to as great a degree as the colours formed by one of the angles of a common equilateral prism of flint glass.

If the plate is now turned round in its own plane, the observer continuing to see the image, the prismatic image will follow the motion of the plate, and perform a complete revolution about the common image, the blue rays always keeping nearest the common image, and the red rays farthest from it. Let the plane be now placed in such a position, that the prismatic image is in the plane of reflexion, and between the common image and the observer, and let the image of the candle be viewed at various angles of incidence. It will then be found, that the angular distance of the prismatic image from the common image gradually increases as the candle is viewed more obliquely, the distance being 2° 7′, when the candle is seen almost perpendicularly in the plate, and 9° 14′, when it is seen at the greatest obliquity. This angular distance varies with more rapidity when the plate is turned round 180°, so as to place the common image between the prismatic image and the observer; but, in this case, we cannot observe the angle much beyond 60°, where it amounts to 4° 30′.

On the outside of the prismatic image will be observed a mass of coloured light, nearly at the same distance beyond the prismatic image that the prismatic image is from the common image. These three images are always in the same straight line; but the angular distance of the mass of coloured light varies according to a law different from that of the prismatic image. At great angles of obliquity, this mass of light has a beautiful crimson colour; at an angle of about 37° it becomes green, and at less angles it acquires a yellow hue, approaching to white, and becomes very luminous. The colours of this mass of light become more brilliant when the plate of mother-of-pearl is polished, and have an origin essentially different from the colours of the prismatic image.

Hitherto we have considered the phenomena only in the case where the surface has merely that slight degree of polish which accompanies smooth grinding. If a greater degree of polish, however, is communicated to the plate, the common image becomes more brilliant, and *a new prismatic image starts up, diametrically opposite to the first prismatic image, and at the same distance from the common image.* This second prismatic image resembles in every respect the first, and follows the same law by a variation of the angle of incidence. Its brilliancy increases with the polish of the surface, and when this polish is very high, the second prismatic image is nearly as bright as the first, which has its brilliancy a little impaired by polishing. This second image is never accompanied, like the first, by a mass of coloured light. If the polish of the surface is removed by grinding, the second prismatic image vanishes, and the first resumes its primitive brilliancy.

When the preceding experiments are repeated on the opposite surface of the plate of mother-of-pearl, the same phenomena are observed, but in a *reverse* order, the first prismatic image and the mass of coloured light being now seen on the opposite side of the plate.

In examining the light transmitted through the mother-of-pearl, we shall perceive phenomena analogous to those which have been described. A coloured image will be seen on each side of the common image, having the same angular distance from it as those seen by reflexion, and resembling them in every particular; the blue light being nearest the common image, and the red light farthest from it. These two images, however, are generally fainter than those seen by reflexion. When the second prismatic image is extinguished by removing the polish, it is then the most brilliant when seen by transmission; and, in general, the image which is brightest by reflexion is faintest by transmission, and *vice versa.*

The phenomena which we have now described must be allowed to be very singular, and contrary to all our notions of the action of surfaces upon light; and had it not been for the accidental circumstance which led to the discovery of their communicability, it is probable that philosophers would have remained satisfied with ascribing them to reflexion from differently inclined planes near the surface of the shell.

In measuring the angular distances of the prismatic image from the common image seen by reflexion, Dr. Brewster had occasion to fix the mother-of-pearl to a goniometer by means of a cement made of rosin and bees' wax. Upon removing it from the cement when in a hard state, by insinuating the edge of a knife, and making it spring off, the plate of mother-of-pearl left a clean impression of its own surface; and he was surprised to observe, that the cement had actually received the property of producing the colours which were exhibited by the mother-of-pearl. This unexpected phenomenon was at first attributed by our author, and by several gentlemen who saw the experiments, to a very thin film of mother-of-pearl detached from the plate, and left upon the cement; but subsequent experiments convinced him that this was a mistake, and that the mother-of-pearl really communicated to the cement the properties which it possessed.

The best method of making this experiment is to employ black sealing-wax, and to take the impression from the mother-of-pearl, when the wax is rendered as fluid as possible by heat. The mother-of-pearl should be fixed to a handle like a seal, and its surface should be carefully deprived of any greasy substance that might accidentally be adhering to it.

The properties of mother-of-pearl may also be communicated in this way to balsam of Tolu, gum-arabic, gold-leaf placed upon wax, tinfoil, the fusible metal composed of bismuth and mercury, and to lead, by hard pressure, or the blow of a hammer. When the impression is first made upon the fusible metal, the play of colours is singularly fine; but the metallic surface soon loses its polish, and the colours gradually decay.

In order to show that in these cases no part of the mother-of-pearl is left on the surface, Dr. Brewster plunged a piece of wax after it had received the impression, into nitric acid. which would instantly have destroyed the carbonate of lime, of which the mother-of-pearl is chiefly composed, but it had no effect either in destroying or diminishing the colorific property of the surface In soft cements, made of bees' wax and rosin, the slightest degree of heat destroys the superficial configuration, by which the colour is produced. In sealing-wax, gum-arabic, and realgar, a much greater heat is necessary to destroy it; but in tinfoil and lead, its destruction can only be effected by the temperature at which they cease to become solid.

If we now examine the prismatic images reflected from the wax which has received the impression from an unpolished piece of mother-of-pearl, we shall find that the single prismatic image which is thus produced is on the right hand side of the common image, whereas it is on the left hand side of the common image in the mother-of-pearl itself.

At different angles of incidence, the two coloured images, formed by the wax, follow the same laws as those produced by the mother-of-pearl; but the mass of green and crimson light never appears; it is therefore caused by some internal structure, which cannot be communicated to other bodies.

When an impression is taken from the fracture of mother-of-pearl, its faculty of producing colour is also communicated. In imparting to gum-arabic and balsam of Tolu the superficial configuration of mother-of-pearl, we are enabled, on account of their transparency, to observe the changes induced upon the transmitted light. The extraordinary images formed by reflexion were both visible—the primary one being remarkably brilliant, and the secondary one scarcely perceptible; but when the light was transmitted through the gum, the primary image was nearly extinct, while the secondary one was unusually brilliant and highly coloured, far surpassing in splendour those which are formed by transmission through the mother-of-pearl itself. When both the surfaces of gum-arabic are impressed with mother-of-pearl, four images are seen. The colours seen by transmission are more brilliant in the gum than in the balsam, as the latter has the greatest reflective power; but the coloured images produced by reflexion do not seem to have suffered a greater dispersion when they are formed by the metals than when they are formed by cements.

From a careful examination of the preceding facts, we must now be prepared to infer, that all the peculiar phenomena of mother-of-pearl, as seen by reflected and transmitted light, have their origin in a particular configuration of its surface;—that the communication of these properties to other bodies is the necessary consequence of the communication of its superficial structure; and that none of the light which is concerned in the production of these phenomena has penetrated the surface of the mother-of-pearl.

In attempting to determine what this configuration of surface is, Dr. Brewster anticipated no assistance from microscopical observations, as it was contrary to all our notions of the action of bodies upon light, to suppose that a plate of mother-of-pearl, having its surface as finely smoothed, and as highly polished, as the lenses of a telescope, could exhibit to the human eye any superficial irregularities. This opinion, however, was erroneous. By the application of single microscopes, with very high magnifying powers, he has discovered in almost every specimen of mother-of-pearl, a grooved structure upon its surface, which produces all the phenomena of communicable colours. This structure resembles, very closely, the delicate texture of the skin at the top of an infant's finger, or the minute corrugations which are often seen on surfaces covered with varnish, or with oil paint.

When the mother-of-pearl has a regular structure, the grooves are always parallel; but when there is any irregularity of configuration, the direction of the grooves varies, and they are arranged in all possible forms, like the veins of agate, or like the lines on the coast of a map, by which the engraver marks a number of inlets and islands.

In some specimens, the spaces between the grooves are so wide, that they can be readily seen with a magnifying power of *six* or *eight* times, and sometimes they may be distinguished by the naked eye. At some parts of the surface, the distance between the grooves is so small, that more than 3000 may be counted in an inch; and in other parts they cannot be detected by any magnifying power which can be applied. When the space between the groves is large, a new groove often commences, and there is frequently a sudden change from a space, with a series of distant grooves to another space, with a series of very close ones. Similar appearances were seen in the structure of pearls. When the mother-of-pearl is scratched or indented, the bottom and sides of the scratches are grooved exactly like the parts that are polished. The grooved structure which has now been described is distinctly seen in wax, gum-arabic, and the metals, after the superficial structure of the mother-of-pearl has been impressed upon them.

The direction of the grooves is, in every case, at right angles to the line joining the common image and the coloured image; and hence, in irregularly formed mother-of-pearl, where the grooves are often circular, and have every possible direction, the coloured images appear irregularly scattered round the ordinary image. In the real pearl these coloured images are crowded into a small space round the common image, partly on account of the spherical form of the pearl; and the various hues are thus blended into a white unformed light, which gives to this substance its high value as an ornament.

Had the grooved structure of mother-of-pearl appeared only upon its external surface, or upon any internal surface exposed by fracture, the phenomena of the communicable colours would have disappeared when any artificial surface was substituted in place of the natural one. But the remarkable and most unaccountable circumstance in mother-of-pearl is, that if we grind down the natural surface with the finest powders, and polish it to the utmost degree of brilliancy, we shall find it impossible to grind out the grooved structure which appeared upon its natural surface. The substance of the mother-of-pearl disappears during the process of grinding, but the superficial depressions, as well as the superficial elevations, are worn away simultaneously, so that the grooved structure cannot be removed but by the entire destruction of its substance.

The colours of striated surfaces,* first observed by Boyle, and those produced by small scratches upon polished substances, are analogous to the communicable colours of mother-of-pearl, and, like them, may be impressed upon wax and other soft substances; but the colours of the integuments of some of the coleopterous insects are not communicable, and are similar to the colours of thin plates.

The mass of coloured light, which always accompanies the first or principal prismatic image, is not affected like the communicable colours, when the light is incident upon the mother-of-pearl, from a fluid of the same refractive power; and therefore it follows, that it has actually penetrated the surface of the mother-of-pearl, and suffered reflexion from the minute laminæ or plates of which it is composed. This class of colours is often highly brilliant, both when seen by reflexion and transmission, but the reflected tints may be developed in a very beautiful manner, by grinding down to the thickness of the *hundredth* or two hundredth of an inch, particular pieces of mother-of-pearl, that are otherwise incapable of exhibiting them. See *Phil. Trans.* 1814. Some interesting observations of Mr. Herschel on mother-of-pearl will be found in the *Edin. Phil. Journ.* vol ii. p. 117.

CHAP. VI.

ON DOUBLE REFRACTION.

The double refraction, and the polarisation of light, have, in consequence of the discoveries of the present century, become a subject of great extent, and resemble more a separate branch of science, than a department of optics. The delicate nature of some of its experimental inquiries, and the mathematical formulæ in which the results have been enveloped, have given it the character of being inaccessible to ordinary minds; and, from these causes, the study of it seems to have been entirely neglected, even by those individuals who have cultivated, with zeal and success, every other branch of natural philosophy. Splendid as the ordinary phenomena of light and colours are allowed to be, and interesting as all those inquiries are which relate to the formation of images, and the principles of optical instruments, yet we venture to assure the reader, that the subject of double refraction and polarisation will introduce him into a new world; and that he will be delighted at every step with the splendour of the phenomena which it presents to him, and with the information which it furnishes, not only respecting the structure and constitution of organized bodies, but respecting that subtle and invisible element which nature seems almost to have placed without the pale of scientific research.

Def. 1. When a ray of light is incident upon glass or water, or any other fluid, whether bounded by one or by two plane surfaces, the image formed by refraction is always single; or, when there is a single incident ray, there is only a single refracted ray. These bodies are therefore said to have *single refraction*. There are various bodies, however, such as *Iceland spar*, *Rock crystal*, &c. which give two images of any object seen through them when they are bounded by plane surfaces, or which give two refracted rays when there is only one incident one. These bodies are said to have *double refraction*, and are called *doubly refracting crystals*.

Def. 2. In doubly refracting crystals, one of the images or pencils is refracted according to the law of the Sines, discovered by Snellius, and therefore the direction of the ordinarily refracted ray in any doubly refracting crystal, may be found from the principles already explained in a preceding chapter. The image or ray so formed is called the *Ordinary* ray or image. The second pencil or image, however, is formed according to a new and entirely different law, and is therefore called the *Extraordinary ray or image*.

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* These colours are finely seen in the light of the sun upon glass smoothly ground with emery; upon smooth water-worn stones, upon wood and polished leather; and almost every substance whose surface is not highly polished.

Def. 3. In all doubly refracting crystals, there is *one* or more lines along which the *double refraction* or the separation of the ordinary and extraordinary images is nothing, or vanishes. This line is called the *Axis* of the *crystal*, or the *Axis of double refraction*.

Def. 4. If the extraordinary ray is refracted *towards the axis of a crystal*, that axis is called a *Positive axis of double refraction;* but if it is refracted *from* the axis, that axis is called a *Negative axis of double refraction*.*

Def. 5. The *principal section* of a crystal is any plane passing through its axis of double refraction.

Sect. I.—*On the Double refraction produced by Crystals with* one *axis.*

Prop. I.

All regular crystals which belong to the rhomboidal or pyramidal systems of crystallization,† or whose primitive forms are the rhomboid with an obtuse summit; the rhomboid with an acute summit; the regular hexahedral prism; the octohedron with a square base; the right prism with a square base; and the bipyramidal dodecahedron,—have *One* axis of double refraction, coincident with the crystallographic axis of these solids.

This general law was determined by Dr. Brewster, from the examination of all the crystallized bodies which belonged to the prismatic forms mentioned in the proposition. The following table of the results of his observations contains the crystals whose primitive forms have been determined by Hauy. The signs + and — denote that the axis of double refraction is *positive* or *negative*.

I. *List of Crystals of known Primitive Forms, and having* one *Axis of Double Refraction.*

1. *Rhomboid with obtuse summit.*

— Carbonate of lime.
— Carbonate of lime and magnesia.
— Rubellite.
+ Dioptase.
— Carbonate of lime and iron.
— Tourmaline.
Ruby silver.

2. *Rhomboid with acute summit.*

— Corundum.
— Sapphire.
— Ruby.
Cinnabar.

3. *Regular hexahedral prism.*

— Emerald.
— Beryl.
— Phosphate of lime.
— Nepheline or Sommite.
— Arseniate of copper.
— Arseniate of lead.

4. *Octohedron with a square base.*

+ Zircon.
+ Oxide of tin.
+ Tungstate of lime.
— Mellite.
— Molybdate of lead.
— Octohedrite.

5. *Right prism with a square base.*

+ Titanite.
— Idocrase.
— Wernerite.
— Meionite.
Uranite.

6. *Bipyramidal dodecahedron.*

+ Quartz.
— Phosphate of lead.
— Phosphato-arseniate of lead.

According to Hauy's *determinations*, the following substances belong to the preceding class of primitive forms; and if his determinations were correct, they would form exceptions to the general law stated in the proposition.

Crystals arranged by Hauy under the Rhomboidal and Pyramidal System.

Sulphate of magnesia Chromate of lead Mesotype	Right prism with a square base.
Carbonate of barytes Carbonate of strontites Iolite	Hexahedral prism.
Cryolite	Octohedron with a square base
Harmotome Chabasie	Obtuse rhomboid.
Sulphate of iron	Acute rhomboid.

Upon examining these minerals, however, Professor Mohs of Freybourg has excluded all of them, with the exception of *Iolite*, from the *Rhomboidal and Pyramidal Systems*, and consequently has enabled Dr. Brewster to remove every objection to the generality of his law, with the single exception of *Iolite*, which will also be found to have a different prismatic form from that which has been assigned to it.

Dr. Brewster has likewise determined that the following crystals have one axis of double refraction; and though their primitive forms are not ascertained, he has predicted, on the faith of the general principle, that they belong to the rhomboidal or pyramidal Systems.

II. *List of Crystals with one Axis of Double Refraction, and whose Primitive Form has not been determined by Crystallographers.*

	Position of the Axis of Double Refraction.
— Mica from Kariat -	Perpendicular to the laminæ.
— Mica with amianthus -	Perpendicular to the laminæ.
— Hydrate of Stronites	Perpendicular to the quadrangular plate.
— Arseniate of Potash -	Axis of quadrangular prism.
— Muriate of Lime -	Axis of hexahedral prism.
— Muriate of strontian -	Axis of hexahedral prism.
— Nitrate of soda -	Axis of obtuse rhomb.
— Sub-phosphate of potash -	Axis of quadrangular prism.
— Sulphate of nickel and copper	Axis of quadrangular prism.
— Hyposulphate of lime (*Mr. Herschel*)	Axis of hexagonal tables.
+ Boracite - -	Axis of cubical rhomb.
+ Apophyllite from Uton -	Axis of prism.
+ Apophyllite surcomposée -	Perpendicular to the plate.
+ Sulphate of potash and iron -	Axis of hexahedral prism,
+ Super acetate of copper and lime.	Axis of prism.
+ Hydrate of Magnesia -	Perpendicular to the laminæ.
+ Ice - -	Axis of hexahedral prism or rhomb.

From the generality of the law stated in the propo-

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[*] The *Positive* axis is called *Attractive*, and the *Negative Repulsive*, by M. Biot, in all his writings; but these names involve a hypothesis which has no existence in nature, and must be altogether abandoned.

[†] See Moh's *Characteristic*.

sition, we may in every case, where the primitive form of the crystal is known, determine not only that it has one axis of double refraction, but also the position of this axis; and *vice versa.* when the axis of any crystal is known, we may infer that it belongs to the first class of primitive forms, and that the axis of double refraction is the axis of the primitive solid. For farther information on this subject, see *Phil. Trans* 1818, p. 210, &c; Wernerian *Memoirs*, vol iii. p 50. 337 read 20th March, 1819. and Aug. 5, 1820; *Journal de Physique*, tom. lxxxix. p. 36 July 1819; *Edinburgh Philosophical Journal*, vol iv. p. 352; v. p. i 217; and Mohs' *Characteristic of the Natural History System of Mineralogy*, Edin. 1820.

Prop. II.

To determine the law of double refraction in all crystals with *One* axis.

As the phenomena of double refraction have been long studied in the crystals of Iceland or calcareous spar, we shall *first* explain the general law obtained experimentally by the celebrated Huygens, in relation to this crystal; and, *secondly*, a more general law, which embraces all other crystals, whether positive or negative.

1. Iceland spar crystallizes in the form of a rhomb, Fig. 13. whose axis AB joins the two obtuse solid angles of the crystal. This axis is also the axis of double refraction, along which, when a ray of light was incident, Huygens found that the separation of the ordinary and extraordinary rays is nothing. In every other position of the incident ray there is double refraction, the amount of which is determined by the following law discovered by Huygens from experiment. the double refraction increasing from the pole to the equator, where it is a maximum.

Let ABEF, Fig. 14. be a piece of Iceland crystal, and let one of the three obtuse angles, which form the solid angle C, namely ACB, be bisected by CG, the plane CGHF will be a *Principal Section of the crystal.*

If the surface AB is now exposed to the sun, being all covered but a small aperture K in CG, and if a ray IK is incident perpendicularly at K, it will be divided at the point K into two rays, one of which KL, will be a continuation of IK, and will be the *ordinary* ray while the other KM, or the *extraordinary* ray, will deviate from KL towards C, by an angle of 6° 40′, but will still be in the plane CGHF. This ray will emerge at M in the direction MZ, parallel to IK Hence, since the point M, by the extraordinary refraction, is seen by the refracted ray MKI, the eye being at I, any point or aperture at L, by the same refraction, will be seen by the refracted ray LKI, LK being parallel to MK, if I is very distant. The point L will consequently be seen in the direction IRS, and as the same point is seen by the ordinary refraction in the direction IK, it will necessarily appear *double*.

If the ray now falls in the direction NO, in the plane CGHF, making an angle of 73° 20′ with CG, or nearly parallel to CF, which makes with FH an angle of 70° 57′. it will be divided at O into two rays, one of which, viz. the *extraordinary* ray, will be a continuation of NO, without refraction, while the other, or the *ordinary* ray, will be refracted in the direction OQ, both rays being in the plane CGHF. This is true of all planes parallel to the principal section, and also of all planes parallel to the principal section that bisects the other angles BCF and ACF.

In order to find the law according to which the double refraction varies at different inclinations with the axis of the crystal, let CGHF, Fig. 15. be any of the *principal sections* of the crystal, or any plane passing through its axis, and SK, VK, two rays incident in that plane on the surface CG of the crystal, and equally inclined to the line IKL, perpendicular to CG at K Then if KM is the refracted ray, belonging to the ray IK, incident perpendicularly, the oblique rays VK, SK will be so refracted that the extraordinary rays KT, KX will cut the base HF in points T and X equidistant from M, or TM=XM.

2. Instead of considering the incident ray as falling upon any natural face of the crystal, let us suppose that any of the crystals of the *negative* class is entirely round, and that AB, Fig. 16. is its axis where the double refraction is nothing, and *c* CD *d* a plane perpendicular to AB, which will cut the sphere ACBD in a line which may be called the equator of double refraction. Then if the ray of light is incident in any direction in this plane, and perpendicular to the spherical surface, so that it may be at right angles to AB the axes, its double refraction is found to be a *maximum*.

Let us now suppose that the index of refraction of the ordinary and extraordinary ray in the plane *c*COD*d* has been accurately measured, and let us call the former m, and the latter m', then Huygens found, that if an ellipse A *c* B *d* is drawn, whose lesser axis AB is to its greater axis *c d* as $\frac{1}{m} : \frac{1}{m'}$; and if an oblate spheroid is generated by the revolution of this ellipse round its lesser axis AB, the variable radii of this spheroid will be the reciprocal of the velocity of the extraordinary ray at different points of the sphere. Thus, if R *a b* O is a ray of light incident at *b*, then the radius O*a* of the spheroid will be a measure of the velocity of the extraordinary ray; and consequently $\frac{1}{\mathrm{O}\,a}$ will be the index of refraction for that ray. Now if we call the angle ROA$=\phi$ and R, r the two axes of the spheroid or R$=c\,d$. and $r=$AB. and v the velocity of the extraordinary ray, it may be shown as Malus has done,* that

$$\frac{\mathrm{R}\,r}{\sqrt{(r^2\,\mathrm{Sin.}^2\,\phi+\mathrm{R}^2\,\mathrm{Cos.}^2\,\phi)}}$$

is the radius O*a* of the spheroid for any angle ϕ. Hence, since the velocity of the extraordinary ray is reciprocally as this radius we have

$$v=\frac{\sqrt{(r^2\,\mathrm{Sin.}^2\,\phi+\mathrm{R}^2\,\mathrm{Cos.}^2\,\phi)}}{\mathrm{R}\,r}, \text{ or}$$

$$v^2=\frac{1}{r^2}-\left(\frac{\mathrm{R}^2-r^2}{\mathrm{R}^2\,r^2}\right)\mathrm{Sin.}^2\,\phi \text{ that is,}$$

If the square of the velocity of the ordinary ray be $\frac{1}{r^2}$, this quantity is *diminished* by another quantity $\left(\frac{\mathrm{R}^2-r^2}{\mathrm{R}^2\,r^2}\right)\mathrm{Sin.}^2\phi$, varying with the inclination of the refracted ray to the axis AB

As Huygens and Malus supposed that all crystals had only one axis of double refraction, they believed the above law to be the universal law of double refraction; but in examining the phenomena of quartz, M. Biot discovered that the extraordinary ray had its index of refraction m' greater than the index of refraction m of the ordinary ray; and he concluded, that in such crystals to which we have given the name of *positive*, the phenomena are represented as in Fig. 17. by a prolate ellipsoid A c B d. Hence it follows, that

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* *Théorie de la Double Refraction*, p. 143.

$$v^2 = \frac{1}{r^2} + \left(\frac{R^2 - r^2}{R^2\, r^2}\right) \text{Sin.}^2 \phi,$$

and that the square of the velocity of the extraordinary ray is now *increased* by the same quantity by which it was diminished in *negative* crystals.

Although our limits will not permit us to insert the investigation of the general formulæ for double refraction given by Malus, yet we shall lay before our readers the formulæ which he obtained.

Let θ = angle of incidence.

θ' = angle of extraordinary refraction.

π = angle which the intersection of the plane of incidence forms with the axis.

π' = the same angle for the ray refracted extraordinarily.

λ = the angle which the axis of the crystal makes with the perpendicular to the plane of incidence.

$A = R^2 \text{ Sin.}^2 \lambda + r^2 \text{ Cos.}^2 \lambda.$

$C = \text{Sin. } \lambda \text{ Cos. } \lambda \, (R^2 - r^2.)$ Then

$$\text{Tang. } \theta' \text{ Cos. } \pi' = \frac{R^2\, r^2 \text{ Sin. } \theta \text{ Cos. } \pi}{A\sqrt{A - R^2. \text{ Sin.}^2 \theta\, (r^2 \text{ Cos.}^2 \pi + A \text{ Sin.}^2 \pi}} + \frac{C}{A},$$

$$\text{and Tang. } \theta' \text{ Sin. } \pi' = \frac{R^2. \text{ Sin. } \theta. \text{ Sin } \pi}{\sqrt{A - R^2. \text{Sin.}^2 \theta\, (r^2 \text{ Cos}^2 \pi + A \text{ Sin}^2 \pi.)}}$$

When the refracting surface is parallel to the axis we shall have $\lambda = 90$, in which case $A = r^2$ and $C = 0$. The formula then becomes

$$\text{Tang. } \theta' \text{ Cos. } \pi' = \frac{r^2 \text{ Sin. } \theta \text{ Cos. } \pi}{R\sqrt{1 - \text{Sin.}^2 \theta\, (r^2 \text{ Cos}^2 \pi + R^2 \text{ Sin.}^2 \pi)}}. \quad (1.)$$

$$\text{Tang. } \theta' \text{ Sin. } \pi' = \frac{R \text{ Sin. } \theta \text{ Sin. } \pi}{\sqrt{1 - \text{Sin.}^2 \theta\, (r^2 \text{ Cos.}^2 \pi + R^2 \text{ Sin.}^2 \pi)}}. \quad (2.)$$

and dividing the one equation by the other, we have

$$\text{Tang. } \pi' = \frac{R^2}{r^2} \text{ Tang. } \pi.$$

When the refracting surface is parallel to the axis, and the plane of incidence perpendicular to the axis, then $\pi = \pi' = 90°$, or $\lambda = 90$; consequently Cos. $\pi' = 0$, and the first equation becomes

$$\text{Tang. } \theta' = \frac{R \text{ Sin. } \theta}{\sqrt{1 - R^2 \text{ Sin.}^2 \theta}}, \text{ and Sin. } \theta' = R \text{ Sin. } \theta.$$

When the refracting surface is parallel to the axis, and the plane of incidence passes through the axis, in which case the refraction is in the plane of a principal section, then $\pi = \pi' = 0°$, the second equation becomes

$$\text{Tang. } \theta' = \frac{r}{R} \times \frac{r \text{ Sin. } \theta}{\sqrt{1 - r^2 \text{ Sin.}^2 \theta}}.$$

or, by substituting r Sin. θ for its equal Sin. θ', we have

$$\text{Tang. } \theta' = \frac{r \text{ Sin } \theta}{\sqrt{1 - r^2 \text{ Sin.}^2 \theta}},$$

which substituted in the general formula gives

$$\text{Tang. } \theta' = \frac{r}{R} \text{ Tang. } \theta.$$

When the refracting surface is perpendicular to the axis of the crystal, then $\lambda = 0°$, and $A = r^2$, and $C = 0$. Hence

$$\text{Tang. } \theta' \text{ Sin. } \pi' = \frac{R^2 \text{ Sin. } \theta \text{ Sin. } \pi}{r\sqrt{1 - R^2 \text{ Sin.}^2 \theta}}.$$

$$\text{Tang. } \theta' \text{ Cos. } \pi' = \frac{R^2 \text{ Sin. } \theta \text{ Cos. } \pi}{r\sqrt{1 - R^2 \text{ Sin.}^2 \theta}}.$$

and dividing the one equation by the other, we have

Tang. π' = Tang. π, and $\pi' = \pi$, which shows that the refracted ray is in the plane of the incident ray. Hence we obtain from the preceding equation,

$$\text{Tang. } \theta' = \frac{R^2 \text{ Sin. } \theta}{r\sqrt{1 - r^2 \text{ Sin.}^2 \theta}}.$$

By means of these formulæ, which Malus deduced from the law of Huygens, that able philosopher has computed the double refraction in various sections of the crystal, and has in every case found, that the results corresponded most accurately with observation. The same law was confirmed by the observations of Dr. Wollaston;—and, by a different method of observation, which became absolutely necessary in crystals like *Arragonite* and others, Dr. Brewster determined that the Huygenian law represented the phenomena in the most accurate manner.

SCHOLIUM.

As we have already given the value of m and m', or the indices of refraction of the ordinary and extraordinary ray, in the table of refractive powers in p. 630, the form of the ellipsoid or spheroid, by which the double refraction of each crystal is represented, may be easily determined, as $R = \frac{1}{m'}$, and $r = \frac{1}{m}$; and the position of its axis of revolution is given by Prop. I. p. 704 of this chapter.

SECT. II.—*On the Double Refraction of Crystals with Two Axes.*

When Malus wrote his *Théorie de la Double Refraction*, and when M. Biot wrote his *Traité de Physique*, crystals with two axes of double refraction were entirely unknown, and the law of Huygens is given in these two works, as the universal law of double refraction.*

In 1816, Dr. Brewster discovered that a great body of crystals had two axes of double refraction. He found, that a double system of rings always accompanied the two axes; and by examining the separation of the images in the same crystal in which he had produced the rings, he had the satisfaction of witnessing, for the first time, that the two images coalesced at the two poles of no polarisation which formed the centres of the two systems of rings; and by measuring the extraordinary refraction at different points of the rings, he found, that the lines of *equal double refraction*, or the *isofringent lines*, as they may be called, were invariably coincident with the *isochromatic curves*, or the *lines of equal tints*. Hence he was put in possession of a method entirely new, of studying the phenomena, and was thus led to determine the general laws of double refraction for all crystals of any number of axes, which we shall now proceed to explain.

In his first inquiries on the subject, he adopted the *apparent axes*, where the double refraction was nothing, as the *real axes*, to which the forces of double refraction were related; but having found that these lines had no relation whatever to any fixed and permanent lines in the primitive forms, and that the tints did not altogether vanish at these points, he abandoned his first hypothesis, and considered these axes as *resultant axes*, where the action of the other two axes were in a state of equilibrium. Thus, if P, P′, Fig. 18. are the poles of no double refraction, he considered the line OO,′ lying in the plane passing through PP′, and equidistant from P, P′, as the principal real axis, while the other axis was in the direction AB, perpendicular to OO′, or in the direction DE, at right angles to both AB and OO′. He then found, that the real axes OO′ and AB, or DE, or the plane DPP′E′, passing through the axes, were in every case, with the exception of *sulphate of lime*, coincident with permanent lines in the primitive forms.

Prop. III.

All regular crystals which belong to the *Prismatic* system of Mohs, or whose primitive forms are the *Right prism*, with its base a rectangle, a rhomb, or an oblique parallelogram;—the *Oblique prism*, with its base a rectangle, a rhomb, or an oblique parallelogram; or the *Rectangular and Rhomboidal Octohedron*, have *Two* axes of double refraction coincident with some permanent line in the primitive form.

The general law stated in this proposition, was determined by Dr. Brewster from the examination of a very great number of crystallized bodies.

The following Table of the results of his observations, contains all those crystals with two axes whose primitive form have been determined by mineralogists.

1. *List of Crystals of known Primitive Forms, and having* Two *Axes of Double Refraction.*

1. *Right Quadrangular Prism.—Base a Rectangle.*

Names of Minerals.	*Position of Principal Axis.*	*Position of Second Axis.*
Cymophane, *Young*.	Axis of right prism.	Perpendicular to the sides.
Peridot, ditto.	Perp. to axis.	Axis of right prism.
Prehnite, ditto.		
Stilbite, ditto.	Parallel to largest side of prism, or perp. to best cleavage planes.	Axis of right prism, or perp. to longest faces.
Comtonite,† *Brooke*.	Perp. to axis of right prism.	Axis of that prism, or other axis.‡
Thomsonite, ditto.	Perp. to axis of prism.	Axis of the prism.
Anhydrite, *Bournon*.	Axis of right prism.	Perp. to sides of prism.
Tartrate of potash, do.	Perp. to the flat rhomb. faces	Parallel to a side of rhomb. prism.
Staurotide, *Hauy*.		
Datholite, do.		
Mica, do.	Axis of right prism.	Greater diagonal of its rhomb. base.
Talc, do.	Axis of right prism.	Diagonal of its rhomb. base.
Spodumene, do.	Axis of prism.	In plane of laminæ.
Sulphate of barytes, do.	Short diagonal of rhomb. base.	Long diagonal, or axis of prism.
Sulphate of strontian, do.	Axis of the prism.	Perp. to axis of prism.
Sulphate of soda, *Bournon*.		
Citric acid, do.		
Tartrate of potash and soda, do.		
Chromate of lead, do.		
Stilbite, *Brooke*.	Perp. to laminæ	In plane of laminæ.
Mesotype of Auvergne, do.	Axis of prism.	Perpendicular to axis.

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[*] In 1811 M. Biot, and in 1812 Dr. Brewster, had discovered the compound polarising structure of *Mica*, which M. Biot at one time attributed to *three* axes of polarisation, and at another time to *two*; and before the *Traité de Physique* was written, its author was acquainted with the existence of a double system of rings in *Topaz* and in *Nitre*, which had been communicated to him, the former in 1814, and the latter early in 1816; but, so far from ever imagining that these bodies had two axes of double refraction, he gave *Topaz* as a crystal with one axis.

[†] See *Edinburgh Philosophical Journal*, vol. iv. p. 131; and vol. vi. p. 112.

[‡] The term *other axis* means, an axis rectangular to the other two.

3. Right Quadrangular Prism.—Base an Oblique Parallelogram.

Names of Minerals.	*Position of Principal Axis.*	*Position of Second Axis.*
Needlestone of Faroe, do.	Axis of prism.	Perpendicular to axis.
Sulphate of lime, *Hauy.*	In plane of the laminæ.	Axis of prism.
Epidote, do.	In base of prism.	Axis of prism.
Axinite, do.		
Heolandite, *Brooke.*		
Brewsterite, do.		
Sulphato-carb. of lead, do.	Perp. to laminæ.	In plane of laminæ.

4. Oblique Quadrangular Prism.—Base a Rectangle.

Borax, *Hauy.*		
Euclase, do.		

5. Oblique Quadrangular Prism.—Base a Rhomb.

Diopside, *Hauy.*	Perpendicular to sides of the prism.	Axis of prism, or other axis.
Augite, do.		
Glauberite.		
Grammatite, do.		
Sulphate of iron, *Wollaston.*		
Super-sulph. of potash, *Bournon.*	Perp. to axis of prism.	Axis of prism.
Acetate of copper, do.	Perp. to axis of prism.	Axis of prism.
Tartaric acid, do.	Axis of prism.	Perpendicular to faces.
Oxalic acid, do.		
Sogar, do.		

6. Oblique Quadrangular Prism.—Base an Oblique Parallelogram.

Feldspar, *Hauy.*		
Kyanite, do.		
Sulphate of copper, do.		

7. Octohedron with a Rectangular Base.

Nitrate of potash.	Axis of octohedron.	Perpendicular to sides of base.
[*]Arragonite.	Axis of prism, or perpendicular to axis of octohedron.	Perp. to sides of base.
Carbonate of lead.	In plane of base of two pyramids.	Axis of the octohedron.
Sulphate of lead.		
[†]Topaz.	Axis of octohedron.	Perp. to sides of rect. base.
Muriate of copper.	Long diagonal of rhomb. base.	Short diagonal of the rhomb. base.

8. Octohedron with a Rhombic Base.

Sulphur, *Hauy.*		
Sphene, do.		
Carbonate of Soda, do.	Diagonal of base through *o* of Hauy. Pl. xxxix.	Axis of octohedron or other axis.

9. Minerals belonging to the Prismatic System of Mohs, and having TWO *axes, but not included in any of the above divisions of Hauy.*

Sulphate of Magnesia, *Mohs.*	Cleaveable diagonal of square base.	Perpendicular to axis, or the other diagonal.
Carbonate of Strontian, do.	Axis of prism.	Perpendicolar to axis.
Carbonate of barytes, do.	Axis of prism.	Perpendicular to axis.
Diallage.	Perpendicular to plates.	Plane of plates.
Harmotome, Petalite, Chabasie.		

10. Cyrstals, whose primitive form has not been determined, but which have been found by Dr. Brewster to have two axes, and which must belong to the Prismatic System of Mohs.

Iolite.	Axis of prism.	Perpend. to axis of prism.
Indurated Talc.	Perpendicular to plates.	In plane of laminæ.
Carbonate of potash.	Plane of axes perpendicular to the flat tables.	In plane of tables.

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[*] *Journal of Royal Institution*, 1817, vol. iv. p. 113.

[†] *Phil. Trans.* 1814.

Names of Minerals.	*Position of Principal Axis.*	*Position of Second Axis.*
Carbonate of copper.		
Sulphate of ammonia.	Axis of hexahed. prism.	Perp. to axis.
——— cobalt.		
——— ammonia, and magnesia.	Shorter diagonal of the rhomboidal base.	Axis of hexagonal prism, or long diag. of rhomb. base.
——— soda and magnesia.		
——— nickel.	Short diagonal of rhomboidal base.	Axis of prism, or other axis.
——— manganese.		
——— zinc.	Axis of rhomboidal prism.	Short diagonal of rhomboidal base.
Oxy-nitrate of silver.	Perp. to rhomb plates.	Long diagonal of rhomboidal plates.
Nitrate of ammonia.		
——— of lime.		
——— of strontian, with water of crystallization.		
——— of copper.		
——— of zinc.		
——— of mercury.		
——— of bismuth.		
Nitrate of lead, certain specimens.	Mr. Herschel, *Edin. Phil. Journ.* vol. ii. p. 184.	
Muriate of mercury.		
——— of magnesia.		
——— of barytes.		
Acetate of lead.	Perpendicular to broad sides of prism.	Axis of prism, or other axis.
——— of zinc.	In plane of hexag. plates.	Perp. to hexag. plates.
——— of soda.		
Mesotype, Greenland.	Axis of prism.	Perp. to axis.
Phosphate of soda.		
——— of iron.	In plane of laminæ.	Perp. to laminæ.
Oxalate of ammonia.	Perp. to axis of prism.	Axis of prism.
Hyper-oxymuriate of potash.	Perp. to rhomb. plates.	Plate of axis in that diag.
Super-oxalate of potash.		
Super-chromate of potash.		
Chrystallized Cheltenham salts.	Axis of prism.	Perp. to axis.
Murio-sulphate of magnesia and iron.	Cleaveable diagonal of its square base.	Axis of prism rather diag.
Benzoate of ammonia.	Perp. to laminæ.	In plane of do.
Benzoic acid.	Perp. to plates.	In plane of plates.
Chromic acid.		
Sulphato-tri-carb. of lead.	Axis of acute rhomb.	In plane of laminæ.
Spermaceti.	Perp. to plates.	In plane of plates.
Boracic acid.	Perp. to hexag. plates.	In plane of plates.
Succinic acid.	Perp. to faces of flat prism.	In plane of these faces.
Super-tartrate of potash.	Perp. to axis of prism.	Axis of prism.
Tartrate of potash and ant.	Perp. to axis of prism.	Axis of prism.
Camphor.		
Lepidolite.	Perp. to laminæ.	Plane of laminæ.
Realgar.		
Yellow Orpiment.	In plane of plate.	Perp. to plates.
Hydrate of barytes.	Perp. to flat plates.	In plane of plates.
Prussiate of potash.	Perp. to rect. laminæ.	In plane of laminæ.
Mother-of-pearl.	Perp. to laminæ.	In plane of laminæ.
Carbonate of ammonia.	Short. diag. of rhomb, and perp. to best cleavage.	Axis of prism, or long diag.
Natrolite.		
Serpentine.		
Hyposulphite of lime.	Mr. Herschel, *Edin. Phil. Journ.* vol. i. p. 15.	

From the results contained in the preceding Table, Dr. Brewster deduced three general conclusions:[*]

1. *That all the combinations of* SULPHURIC, TARTARIC, *and* ACETIC *acids, with single, earthy, metallic, and alkaline bases, have* TWO *axes of double refraction.*[†]

2. *That the two* APPARENT *axes of crystals with* TWO *axes have no symmetrical relation, either with the faces or prominent lines of the primitive or secondary forms of minerals.*

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[*] See *Phil. Trans.* 1818. p. 223.

[†] The same is true of the *Nitric* acid, with the exception of nitrate of soda; and also of the *Oxalic*, *Benzoic*, and *Boracic* acid, so far as their combinations were examined.

3. *That the* TWO RECTANGULAR *axes, the principal one of which is in the same plane with the two apparent axes, and* EQUIDISTANT *from them, have a constant symmetrical relation to the faces and axes of the primitive forms in which they crystallize.*

PROP. IV.

To determine the law of extraordinary refraction in all crystals with *Two* axes of double refraction.

Before determining the law of extraordinary refraction for this class of bodies, it became necessary to ascertain the position of the real axes to which the phenomena were related. Dr. Brewster at first assumed the two apparent axes P, P′, Fig. 18. as the real axis of double refraction; but he was led to abandon this hypothesis, when he found that in many crystals the colours were not placed symmetrically round the apparent axes; that these axes were not symmetrically related to any prominent lines in the primitive forms; and that the phenomena could not be calculated, by assigning to each axis a force varying according to the Huygenian law. He therefore tried to represent the various and complicated phenomena, by assuming as the real axes two rectangular axes, the principal one of which was OO′, Fig. 18. equidistant from P and P, and in the same plane, and another axis at right angles to OO′.

If the axis OO′ is *positive*, then if we assume AB as the second axis, it must be *positive* also; but if we assume DE as the second axis, it must be taken *negative*, and the results will be exactly the same. Having found, as will be particularly explained in the next chapter, that the tints, or *isochromatic lines*, could be calculated by the application of the parallelogram of forces, (see p. 727,) he obtained the following law for the tints: “ *The tint produced at any point of the sphere by the joint action of two axes, is equal to the diagonal of a parallelogram, whose sides represent the tints produced by each axis separately*, and whose angle is *double of the angle formed by the two planes passing through that point of the sphere and the respective axis.*” But as the *isofringent* lines have the same form as the *isochromatic* curves, and as the doubly refracting forces follow the polarising forces in all their variations, Dr. Brewster proceeded in the following manner to obtain the general law of double refraction.

Take $b =$ the axis of revolution of the two spheroids a, a', the other axis $\beta\ \beta'$ the inclination of the incident ray to the axes of the crystal, ψ the angle of the forces as found in p. 728, and ζ half the difference of the angles at the base of the parallelogram of forces. Then since the velocity of the light is inversely as the variable radius of the spheroid, $\frac{1}{b^2}$ will be the square of the velocity of the ordinary ray, and $\frac{1}{a^2}\ \frac{1}{a'^2}$ the square of the minimum velocity of the extraordinary ray in virtue of the separate action of each axis. The difference between the squares of the velocities of the ordinary and extraordinary rays will be

$$\left(\frac{a^2 \pm b^2}{a^2\ b^2}\right) \text{Sin.}^2\ \beta$$

$$\left(\frac{a'^2 \pm b^2}{a'^2\ b^2}\right) \text{Sin.}^2\ \beta'$$

the sign being positive when the axis is positive, and *vice versa*. But as these expressions represent the sides of the parallelogram of forces we have

$$\text{Tang.}\ \zeta = \frac{\left(\frac{a^2 \pm b^2}{a^2\ b^2} \text{Sin.}^2\ \beta - \left(\frac{a'^2 \pm b^2}{a'^2\ b^2} \text{Sin.}^2\ \beta'\right)\right) \text{Tang.}\ \tfrac{1}{2}\ \psi}{\frac{a^2 \pm b^2}{a^2\ b^2} \text{Sin.}^2\ \beta + \frac{a' \pm b^2}{d'^2\ b^2} \text{Sin.}^2\ \beta'}$$

Consequently the difference between the squares of the velocities of the ordinary and extraordinary ray produced by the combined action of the two axes, will be

$$\frac{\left(\frac{a^2 \pm b^2}{a^2\ b^2} \text{Sin}^2\ \beta\right) (\text{Sin.}\ \psi}{\text{Sin.}\ (\zeta + \frac{1}{2}\psi)}$$

Hence, calling V the velocity required, we have

$$V^2 = \frac{1}{b^2} \pm \frac{\left(\frac{a^2 \pm b^2}{a^2\ b^2} \text{Sin.}\ {}^2\beta\ (\text{Sin.}\ \psi\right)}{\text{Sin.}\ (\zeta + {}^1\psi)}, \text{ and}$$

$$V = \left(\frac{1}{b^2} \pm \frac{\left(\frac{a^2 \pm b^2}{a^2\ b^2} \text{Sin.}\ {}^2\beta\right)\ (\text{Sin.}\ \psi)}{\text{Sin.}\ (\zeta + \frac{1}{2}\psi)}\right)^{\frac{1}{2}}$$

The form of the compound, or irregular spheroid, may therefore be computed for all doubly refracting crystals.

The general law of double refraction which has now been explained, may be thus expressed.

The increment of the square of the velocity of the extraordinary ray, produced by the action of two axes of double refraction, is equal to the diagonal of a parallelogram whose sides are the increments of the square of the velocity produced by each axis separately, and calculated by the law of Huygens, and whose angle is double of the angle formed by the two planes passing through the ray and the respective axes.

When the two axes are of equal intensity, and of the same character, the preceding law gives the very same results as the law of Huygens does for one axis placed at right angles to the other two.

If we call ϕ, ϕ' the angles between the point of the sphere and the resultant axes, the preceding formula will give $V = (v^2 + a\ \text{Sin.}\ \phi \times \text{Sin.}\ \phi')^{\frac{1}{2}}$, v being the velocity of the extraordinary ray, and a a constant coefficient. As the resultant axes, however, are not fixed points, (see p. 730,) but vary in position in the same crystals for different rays, the quantities Sin. ϕ and Sin. ϕ' are not constant, even for the same point of the sphere, and consequently this simplification of the formula has no advantages. See p. 619, col. 2, and p. 730, col. 2.

Sect. III. *On Crystals with* THREE *Axes of Double Refraction.*

Prop. II.

All those crystals which belong to the Tessular System of Mohs, or which have for their primitive form the *Cube*, the *Regular Octohedron*, and the *Rhomboidal Dodecahedron*, have THREE axes of double refraction.

In considering the general principles of the resolution and composition of doubly refracting and polarising axes, Dr. Brewster found that if a crystal had *three equal and rectangular axes*, either all positive or all negative, their combined actions at any point of the sphere would be in equilibrio, and consequently such crystals would have the appearance of being entirely destitute of double refraction.

Under these circumstances, the question naturally arises, whether such crystals have three axes of double refraction, or have no axis at all, any more than a mass of water or a piece of annealed glass; and there are fortunately some principles to guide us in such an enquiry.

Had the doubly refracting forces of rhomboidal crystals, for example, gradually diminished as their primitive forms approached to that of the *Cube*, which is the limit between the acute and the obtuse rhomboids, then we might have expected that the limiting forms would be destitute of double refraction; but this is not the case, and so completely different is the structure of a rhomb, when it is on the eve of passing into the cube, that Dr. Brewster has actually discovered an example of a new primitive form, viz. the *Cubical Rhombohedron*, existing in the *Boracite*,* and possessing a distinct axis of double refraction in the direction of one of its diagonals, or the axis of the cubical rhombohedron. In the *Boracite*, therefore, the optical structure is related to a single axis, while in the *True Cube* the structure is related to three separate axes, one of which is perpendicular to each pair of its square forces.

But as all crystals with ONE or TWO axes have their axes symmetrically placed in relation to the axes of the primitive prism; so, in like manner, the *Cube*, the *Octohedron*, and the *Rhomboidal Dodecahedron*, are the only regular geometrical solids in crystallography, in which neither more nor less than three equal rectangular axes can be placed symmetrically. In the *Cube*, for example, each of three axes is perpendicular to the three pair of square surfaces by which the solid is contained. In the *Regular Octohedron*, each of them coincides with the line which joins the six solid angles of the figure; and in the *Rhomboidal Dodecahedron*, each of the rectangular axes passes through the six solid angles, each of which is contained by four acute angles of the rhomboidal planes.

But independently of these general principles, there are some facts which bear directly upon the point under consideration. Dr. Brewster has found, in almost every crystal that has the *Cube*, the *Regular Octohedron*, and the *Rhomboidal Dodecahedron* for their primitive form, obvious indications, as it were, of *unbalanced action*, and distinct portions of both positive and negative doubly refracting structures.† M. Biot‡ has indeed remarked that these effects may be produced by heat or rapid evaporation; but had he repeated the experiments, he would have found such an explanation completely excluded. In the phenomena produced by *heat*, by *rapid cooling*, and by *evaporation*, the axes are constantly related to the edges or surfaces where the heat or cold is applied; but in the cubical and octohedral crystals, the axis of the polarising portions have no such relation; and, what is decisive of the question, Dr. Brewster took a large crystal of *Alum* with his own hands out of the tub in which it had been freshly crystallized; and though this crystal was neither exposed to pressure nor to heat, it displayed distinctly many portions of a doubly refracting structure related to the axes of its primitive form.

Dr. Brewster has, at considerable length, explained the way in which these unbalanced actions are produced.§ He has imitated them artificially; and in a more recent paper he has shown that certain remarkable phenomena in *Apophyllite*, observed by Mr. Herschel, are the calculable results of the unbalanced action of three rectangular axes. See p. 730.

Having thus endeavoured to show that the partial absence of double refraction, in this class of crystallized bodies, arises from their possessing three rectangular axes of nearly the same intensity, we shall now proceed to establish the truth contained in the proposition, by the following list of crystals which have no regular double refraction.

V. *Crystals whose primitive form is Tessular.*

Cube	Muriate of soda, *Hauy*.	No regular double refraction.
	Amphigene, *Hauy*. Analcime, *Hauy*. Boracite, *Hauy*. Arseniate of iron, *Mohs*.	These crystals have no regular double refraction.
	Aplome, *Mohs*.	Has imperfect double refraction.
Regular octohedron	Diamond, *Hauy*. Fluor spar, *Hauy*. Muriate of Ammonia, *Hauy*. Sulphate of Alumine, *Hauy*. Spinelle, *Hauy*. Pleonaste, *Hauy*. Ruby Copper, *Hauy*. Helvin, *Mohs*.	These crystals have no regular refraction.
Rhomboidal dodecahedron	Garnet, *Hauy*. Blende, *Hauy*. Sodalite, *Mohs*.	These crystals have no regular double refraction.

The relation between the tessular system of crystallization, and the want of regular axes of double refraction, is sufficiently established by the preceding table, though, in the case of the *Cube* alone, the evidence is quite defective; as no fewer than *three* out of *five* crystals have regular axes, viz. *Analcime*, *Amphigene*, and *Boracite*; but Dr. Brewster has proved, that the first is a compound crystal of a very singular kind, and the last a cubical rhombohedron, so that amphigene forms the only real exception; and it will no doubt be speedily found, that it belongs to the prismatic system of crystallization.

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* See *Edinburgh Philosophical Journal*, vol. v. p. 217.

† See *Edinburgh Transactions*, 1815, vol. viii. p. 157.

Traité de Physique, tom. iv. p. 573.

§ *Phil. Trans.* 1818, p. 257.

The following is a List of Crystals which Dr. Brewster has found to have no regular Axes of Double Refraction, and will therefore belong to the Tessular System of Mohs.

Hauyne.
Essonite.
Cinnamon-stone.
Nitrate of lead.
Nitrate of strontian. Octohedral.
Nitrate of barytes.
Nitrite of lead. Octohedral.
Muriate of potash.
Sulphate of alumine and ammonia.

SCHOLIUM.

The Abbé Hauy has remarked, in his *Traité de Mineralogie*. (tom. i. p. 232) that all substances whose integrant molecule is remarkable for its symmetry, have *simple* refraction, such as those which have for their primitive form the cube, the regular octohedron, and the rhomboidal dodecahedron. The meaning of this must be, that *very few* of these bodies which he tried had simple refraction; for in the same volume, and a few pages after he makes the remark, he gives a regular list of doubly refracting crystals, amounting to *nineteen*, which is immediately followed by another *List of Crystals that have no Double Refraction*, and which we shall print as he has given it.

Substances which, when submitted to Experiment, present only Single Refraction, according to Hauy.

1. Fluor spar.
2. *Phosphate of lime.*
3. *Telesie.*
4. Spinelle.
5. Garnet.
6. *Amphigene.*
7. *Tourmaline.*
8. *Axinite.*
9. *Disthene.*
10. Blende.

Now, it is very strange that Hauy should have deduced the above conclusions from only *four* crystals, *fluor spar*, *spinelle*, *garnet*, and *blende*. The other *six* crystals belong to other primitive forms; and as these six have distinct axes of double refraction, it necessarily follows, from Hauy's own facts, that *simple* refraction was not a property of any one class of bodies more than another; and, indeed, he himself states, in the most distinct terms, the converse of this proposition, when he remarks, "*J'ai trouvée qu'il n'y avoit aucune classe de Mineraux qui n'offrit des corps doués de la Double Refraction.**

The incompatibility between M. Hauy's conclusions and his own facts, will appear in a still more striking point of view from his list of transparent crystals, whose primitive form is the *Cube*, viz.

Boracite.
Muriate of soda.
Amphigene.
Analcime.
Scheelin calcaire.
Oxide of Tin.

Every one of which have regular double refraction, with the single exception of *Muriate of Soda*.

As the phenomena of double refraction in various bodies can easily be studied, from their relation to the phenomena of polarisation, we shall now proceed to the subject of the *Polarisation of Light*, as exhibited both by *crystallized* and *uncrystallized* bodies, and shall treat, under that head, of various subjects, which properly belong to the present chapter.

CHAP. VII.

ON THE POLARISATION OF LIGHT.

In the preceding chapter, we have considered merely the separation of the two images as the characteristic of double refraction; but this property of bodies is invariably accompanied with another no less remarkable, namely, the *polarisation* of the two pencils produced by double refraction.

SECT. I. *On the Polarisation of Light that has suffered Double Refraction.*

DEF. The term *polarisation* is employed to express a property which may be communicated to ordinary light, and in virtue of which it exhibits the appearance of having *polarity*, or *poles* possessing different properties.

PROP. I.

To explain the general phenomena of the polarisation of light, as exhibited in *Calcareous spar*, where the two images are distinctly separated.

The discovery of the polarisation of light in doubly refracting crystals, was made by Huygens, after he had completed his treatise on double refraction.

Having taken two pieces of Iceland crystal, and held them with a space between, he found that if all the sides of the one piece were parallel to those of the other, as in Fig. 19 the two pencils, BC, BD, formed by the double refraction of the ray AB, were not doubly refracted in passing through the second crystal in the lines EF, GH ; the pencil DG, which had been *regularly* or *usually* refracted by the first crystal, being now only *regularly* refracted by the second, while the pencil CE, which had been *extraordinarily* or *unusually* refracted by the first, was only *extraordinarily* refracted by the second The very same result took place, not only in the position shown in the figure, but in all other positions, where the principal sections of the two crystals were in the same plane, and whether the two surfaces were parallel or not. "Now, it is wonderful," says Huygens, "why the rays CE and DG, incident from the air upon the lower crystal, should not divide themselves like the first ray AB. One would say that the ray DG, in passing through the upper crystal, must have lost what was required to move the matter which served for the extraordinary refraction; and, in like manner, that CE had lost what was necessary to move the matter which served for the ordinary refraction. There is, however, another fact which overturns this reasoning, which is, that when we arrange the two crystals, so that the planes which form the principal sections cut one another at right angles; then, whether the surfaces are parallel or not, *the ray* DG, *which proceeds from the ordinary refraction, suffers only the extraordinary refraction in the lower crystal, and the ray*

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* *Traité de Mineralogie*, tom. i. p. 232.

CE, *which proceeds from the extraordinary refraction, suffers only the ordinary refraction.* But in all the other positions, infinite in number, besides those which I have determined, the rays DG, CE, divided themselves into two by the refraction of the lower crystal, so that, from the single pencil AB there are formed four pencils, sometimes of equal brightness, and sometimes of different brightnesses, according to the different positions of the crystals, but which do not seem to have more light when taken all together than the single ray AB."

From these facts, as given by Huygens, Sir Isaac Newton concluded, that every ray may be considered as having *four sides* or *quarters*, two of which, opposite to one another, incline the ray to be refracted after the usual manner, as often as either of them are turned towards the coast, or side of double refraction, and the other two wherever either of them are towards the coast of unusual refraction, do not incline it to be otherwise refracted than after the usual manner. The two first may therefore be called the *sides* of unusual refraction, and every ray of light may be considered as having two opposite sides originally endued with a property on which the unusual refraction depends, and the other two opposite sides not endued with that property.

Prop. II.

To determine the law according to which the light of the images varies; when the principal sections pass from a state of coincidence to a position where they are at right angles to one another.

The variation in the intensity of the images formed by two doubly refracting crystals, was first investigated by Malus; but, excepting the case where the incident ray falls perpendicularly upon the first rhomboid, the investigation is too complicated for a popular article like the present. Calling

$o =$ the ray refracted *ordinarily* by the *first* crystal.
$e =$ the ray refracted *extraordinarily* by the *first* crystal.
$o\,o =$ the ray refracted *ordinarily* by the *first* crystal, and *ordinarily* by the *second.*
$o\,e =$ the ray refracted *ordinarily* by the *first* crystal, and *etxraordinarily* by the *second.*
$e\,e =$ the ray refracted *extraordinarily* by the *first* crystal, and *extraordinarily* by the *second.*
$e\,o =$ the ray refracted *extraordinarily* by the *first* crystal, and *ordinarily* by the emergent *second.*
$Q =$ the quantity of light contained in the incident ray
$(1-m)\,Q =$ the quantity of light absorbed by the first crystal.
$P =$ the intensity of any of the pencils.
$P_o =$ the intensity of the *ordinary* ray.
$P_e =$ the intensity of the *extraordinary* emergent ray.

Then, since the quantity of light contained in the two emergent rays is equal to the incident light diminished by the quantity absorbed, we shall have $Q - (1-m)\,Q = m\,Q$; and since the light is equally divided between the two pencils, we obtain $P_o = \frac{1}{2}\,m\,Q$ and $P_e = \frac{1}{2}\,m\,Q$.

But the quantity of light $m\,Q$ which falls upon the second rhomboid, will be reduced by absorption to $m\,Q - (1-m)\,m\,Q = m^2\,Q$; consequently, if a is the angle formed by the principal sections of the two crystals, we shall have

First pencil, $P_{oo} = \frac{1}{2}\,(m^2\,Q\,\text{Cos.}^2\,a)$. Second pencil, $P_{o\,e} = \frac{1}{2}\,(m^2\,Q\,\text{Sin.}^2\,a.)$
Third pencil, $P_{e\,e} = \frac{1}{2}\,(m^2 Q\,\text{Cos.}^2 a)$. Fourth pencil, $P_{e\,o} = \frac{1}{2}\,(m^2\,Q\,\text{Sin.}^2\,a)$.

When the principal sections of the two crystals are parallel, then $a=0$, and $\text{Sin.}^2\,a=0$, consequently $P_{o\,e}=0$, and $P_{eo}=0$; that is, the *third and fourth pencils will disappear.*

When, on the contrary, the principal sections are at right angles to one another, $a=90°$, and $\text{Cos}\,^2 a=0$, consequently $P_{oo}=0$, and $P_{ee}=0$; that is, the *first and second pencils will disappear.*

If the incident ray is not perpendicular to the surface of the first rhomboid, the intensities of the light are different from what is given by the preceding formulæ, and they are functions of the angles of incidence, and of the angle which the ray forms with the principal sections; but for the investigation of this part of the subject we must refer the reader to Malus's *Théorie de la Double Refraction*, p. 207, § 44.

Scholium.

It is obvious, from the facts contained in the two preceding propositions, that the difference between *Direct light*, and light that is *polarised* by the action of a crystal, is, that the *former* may always be divided into two pencils by a doubly refracting crystal, whereas, in the *latter*, this division depends on the angle formed by the principal sections of the two crystals.

The effects described in the proposition may be produced by combining any two *positive*, or any two *negative* crystals; but, if the one is *positive*, and the other *negative*, then the same effects are produced when the principal sections are at right angles, as when they are parallel in the other cases, and *vice versa.*

Sect. II.—*On the Polarisation of Light by Reflexion.*

From the time of Huygens to the year 1810, a period of 132 years, not a single fact was added to our knowledge of the polarisation of light. The discoveries of Malus, however, gave a vigorous impulse to this branch of knowledge; and we shall endeavour, in this and the following section, to give a brief account of the important discoveries by which the single fact discovered by Huygens has been expanded into a new science.

Prop. III.

When a ray of light is reflected at a particular angle from the surfaces of transparent bodies, whether solid or fluid, it is polarised like one of the pencils formed by doubly refracting crystals.

Let a ray of light RS, Fig. 20. proceed from the sun, and fall upon a piece of plate glass AB, at an angle RSP of incidence of about 54° 35′. If the reflected ray ST is received upon the first surface of a rhomb of Iceland spar, it will not be divided into two pencils, either when the principal section of the rhomb is parallel to the plane of reflexion RST, or when it is perpendicular to this plane; but in every intermediate position of the rhomb, the pencil ST will be divided into two, exactly in the same manner as if it had been one of the pencils formed by another rhomb of Iceland spar.

In order to analyze this remarkable fact more completely, Malus placed the principal section of a crystal of calcareous-spar in a vertical direction, and after having divided by it a ray of direct light into *two* pencils, he allowed these two pencils to fall upon the surface of *Water* at an angle of 52° 45′ (the angle at which he had found *Water* to polarise the incident light) The ordinary ray was refracted at the surface of the water, and part of it reflected like all other light; but the extraordinary ray *penetrated the water entirely: Not one of its particles escaped refraction and none of them suffered reflexion.* When the principal section of the crystal, however, was perpendicular to the plane of incidence, the extraordinary ray only produced a partial reflexion, and the ordinary ray penetrated the water entirely, without suffering any reflexion.

When the ray of *direct* light RS, Fig. 2. fell upon the first surface MN of a plate of glass, MN $n\,m$, and was polarised after reflexion in the direction ST, Malus observed that the refracted portion S s reflected at s from the second surface, and emerging at σ in the direction σ T, parallel to ST, was also polarised simultaneously with ST, although the angle S $s\,p$ was much less than RSP, the sine of the first angle being to the sine of the second as the sine of incidence to that of refraction. Hence it follows, that a plate of glass, or any other transparent substance, polarises simultaneously the light that falls upon both its surfaces, when it is incident on the first at the proper angle, and may therefore be substituted in place of a surface of water in all experiments of this kind.

Malus found that *black marble*, *ebony*, and other opaque bodies, polarised light by reflexion like transparent ones. He found that the angle of incidence at which this property was communicated was greater than the bodies of a high refractive power; and he measured, with considerable accuracy, the polarising angles of glass, water, and other bodies. In order to discover the law which regulated the phenomena, he compared these angles with the dispersive powers of glass and water. Finding that there was no relation between these properties of transparent bodies, he draws the following general conclusion: "The polarising angle neither follows the order of the refractive powers, nor that of the dispersive forces. It is a property of bodies independent of the other modes of action which they exercise upon light."*

PROP. IV.

To determine the manner in which a polarised ray is reflected from a plate of glass, having a rotatory motion round the polarised ray, and forming with it a constant angle.

Let ST, Fig. 20, be the ray polarised by reflexion from AB; the incident ray RS being supposed to proceed from the sun when due *south*, for the sake of illustration, and let it be received upon a second plate CD, so that the angle of reflexion from CD, viz. TV, may be always equal to the angle of reflexion from AB, viz. PST, and let us suppose that the plate CD revolves round the ray ST, preserving its inclination to it invariable. Then, in the case represented in the figure where the second plate CD faces the south, and causes the plane of the second reflexion from CD to be parallel to the plane of the first reflexion from AB, the ray ST will suffer partial reflexion in the direction TV, as if it had been common light. If the plate is now turned round ST in different azimuths, so that its face begins to turn to the *east*, the intensity of the reflected pencil TV will gradually diminish; and when it has performed a revolution of 90°, or has its face turned towards the *east*, the pencil TV will *disappear entirely, not a single ray of it suffering partial reflexion*, in which case the plane of reflexion from CD is at right angles to the plane of reflexion from AB. By continuing to turn the plate, the ray TV will re-appear, and will gradually increase in intensity till the plate has turned round 180° from the beginning of its motion, in which case the plane of reflexion from CD will be again parallel to the plane of reflexion from AB, and the reflected ray TV will then be a maximum, as it was at the commencement of its motion. By continuing to turn the plate, the reflected ray will *again disappear* at an azimuth of 270°, and will regain its maximum upon returning to 360°, or 0°, the point from which it set out.

It is obvious from Fig. 1. that in the two positions of the plate CD, when the ray TV is a maximum, viz. at 0°, and 180° of azimuth, the inclination of the two plates of glass is $180 - (90^\circ - 54^\circ\,35' + 90^\circ - 54^\circ\,35') = 70^\circ\ 50'$ in the first case, and that they are parallel in the second case.

In the azimuth of 90° and 270°, where the ray TV entirely disappears, the inclination of the plates will be represented by $\text{Cos.}\,\varphi = \text{Cos.}^2\,\theta$, where θ is the angle of polarisation, in this case 54° 35′, and ϕ the inclination of the plates, which will be found to be 70° 22′ 35″.

Hence it follows, that if we take two plates of glass, inclined to one another at a fixed angle of 70° 22′ 35″, and conceive a line drawn from the first plate to the second, so as to make with both an angle of 35° 25′, and whose projection upon both will form, with their common intersection, an angle of 30° 5′ 30″, every ray reflected by one of the plates of glass parallel to this line will suffer no reflexion from the second, but will wholly penetrate it. On both sides of these angles this effect will cease to be produced, but the farther we go from the limits in either direction, the more will the quantity of the reflected light increase.

The variation of the intensity of the reflected light in passing from the minimum to the *maximum*, may be represented by supposing it proportional to the square of the cosine of the angle of azimuth, or to any even power of the cosine. Thus, if a is the angle of azimuth, which the plane of the second reflexion makes with the plane of the first, I the maximum intensity of the reflected pencil TV, and P the intensity of the pencil corresponding to any azimuth a, then $P = I\,\mathrm{Cos.}^2\,a$, or $P = I\,\mathrm{Cos.}^4\,a$. By taking a successively equal to 0°, 90°, 180°, 270°, it will be seen that either of these formulæ represent the different phenomena which have been above explained. Thus, if $a = 0°$, then $\mathrm{Cos.}\,a = 1$, $\mathrm{Cos.}^2\,a$, or $\mathrm{Cos.}^4\,a = 1$, and $P = 1$, that is, the reflected pencil is at its maximum; and if $a = 90°$, then $\mathrm{Cos.}\,a = 0$, and $\mathrm{Cos.}^2 a = 0$, or $\mathrm{Cos.}^4\,a = 0$, and $P = 0$, that is, the reflected pencil entirely disappears.

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* "Il a determiné sur beaucoup des substances l'angle de reflexion sur laquelle la lumiere incidente est la plus complettement polarisé, et il a reconnu que cet angle ne suit ni l'ordre des puissances refractives ni celui des forces dispersives. C'est une proprieté des corps independans des autres modes d'action qu'ils exercent sur la lumiere. Apres avoir reconnu l'angle sur lequel ce phenomene a lieu pour differens corps pour *l'Eau* et la *Verre* par example il a cherché celui sou lequel la meme phenomene aurait lieu a leur surface de separation lorsqu'ils sont en contact. Il lui reste à determiner la loi suivant laquelle ce dernier angle depend de deux premiers. *Bulletin des Sciences par la Soc. Phil.* June, 1811, No. 45, tom. ii. p. 294.

The two preceding propositions contain the two principal discoveries of malus.

SCHOLIUM.

If, in the azimuth of 90°, when the ray TV entirely disappears, we breathe upon the plate AB or CD, so as to communicate to either a thin film of aqueous vapour capable of reflecting light, the ray TV will be revived. This effect arises from the polarising angle for water being 52° 48′, whereas it is 56° 45′ for glass.

If AB is made to receive the ray of a candle RS, at an angle of 52° 45′, and CD the ray ST at an angle of 56° 45′, then it is obvious that the image of a candle will be seen in the direction VT, because the ray ST is not polarised by the plate AB. If we now, however, breathe upon AB, the image of the candle seen along VT, will disappear, because the ray ST being reflected from water is now polarised. Hence, if we place beside one another two sets of reflectors arranged as above described, we may by breathing upon the two contiguous mirrors exhibit the paradoxical effect of reviving and extinguishing the rays by the same breath. See *Edin. Phil. Journal*, vol. vii. p. 146.

PROP. V.

A ray of white light will be completely polarised by a single reflexion from transparent bodies of all kinds, or the quantity of polarised light in it will be a maximum when the reflexion is made at such an angle that *the tangent of the angle of incidence is equal to the index of refraction.*

While repeating the experiments of Malus in the summer 1811, Dr. Brewster measured the polarising angles of a great number of transparent bodies, and in 1813 and 1814, he endeavoured to connect them by some general principle. The measure for *Water* and the *precious stones* afforded a surprising coincidence between the cube roots of the indices of refraction and those of the tangents of the polarising angles, but the results for glass resisted every method of classification. Having afterwards found, however, that glass often acquires by exposure to the air an incrustation, or experiences a decomposition, which alters its superficial action upon light, and consequently its polarising angles, without altering its refractive power, Dr. Brewster neglected it altogether, and employed only the surfaces of other bodies. In this way he obtained the results, in the following table; and in November, 1814, was enabled to establish the law contained in the proposition.

Table containing the calculated and observed polarising angles for various bodies.

Names of the Bodies.	Calculated polarising angles for the *first* surface.	Observed polarising angles for the *first* surface.	Difference between the calculated and observed angles.	Calculated polarising angles for the *second* surface.
	° ′ ″	° °		° ′ ″
Air*	45 0 32	45 or 47		44 59 28
Water . . .	53 11 0	52° 45′	0° 26′ —	36° 49′
Fluor spar . .	55 9 0	54 50	0 19 —	34 51
Obsidian . .	56 6 0	56 3	0 3 —	33 54
Birdlime . .	56 40 0	56 46	0 6 +	33 20
Sulphate of lime	56 45 0	56 28	0 17 —	33 15
Rock crystal .	56 58 0	57 22	0 24 +	3 2
Opal coloured glass . . .	58 33 0	58 1	0 32 —	31 27
Topaz . . .	58 34 0	58 40	0 6 +	31 26
Mother-of-pearl	58 50 0	58 47	0 3 —	31 10
Iceland spar .	58 51 0	58 23	0 28 —	31 9
Orange coloured glass . . .	59 28 0	59 12	0 16 —	30 32
Spinelle ruby .	60 25 0	60 16	0 9 —	29 35
Zircon . . .	63 0 0	63 8	0 8 +	27 0
Glass of antimony	64 30 0	64 45	0 15 +	25 30
Sulphur . . .	63 45 0	64 10	0 25 +	26 15
Diamond . .	68 1 0	68 2	0 1 +	21 59
Chromate of lead	68 3 0	67 42	0 21 —	21 56

The observations contained in the preceding table establish in a very striking manner the truth in the proposition. The results given in the table were the mean of a great number of observations; and when the reflecting surfaces were faces of cleavage newly laid open, as they should always be when it is practicable, the measures were wonderfully coincident. The method by which the measures were taken consisted in placing the crystalline plate upon the goniometer represented in Plate CCXXIV. Fig. 2. and turning it round till the light of a candle, limited by an aperture, and placed at a considerable distance from the goniometer, was completely polarised, which was indicated by one of the images vanishing when viewed with a rhomb of Iceland spar. The indication of the vernier was then noted, and the graduated circle turned round, till the reflected and direct images of the luminous body coincided. The complement of the arch described by the index was then the angle of polarisation. When the surface of the reflecting body was not very flat, the point upon the wall through which the polarised image was projected was marked, and the angle was obtained by measuring the arch between that point and the candle, by means of a flat surface of glass fixed beside the polarising body. In this way the observations were made with great facility and accuracy without any measurements, and the repetition of the observations became extremely easy and rapid.

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* This observation on *Air* was made by M. Arago, who communicated it to Dr. Brewster in August 1814, as *between 45° and 47°*, and of which a written memorandum was taken in his presence. M. Biot, in his *Traité de Physique*, tom. iv. p. 289, has *omitted entirely the 47°*, which we trust he will replace in the next edition of his work.

By a method which will be afterwards explained, Dr. Brewster measured the polarising angle of water for the *mean yellow rays* obtained from the Monochromatic lamp, and obtained the following result:—

Polarising angle of water,	63°	6′	Dr. Brewster.
	53	4½	M. Biot.
	53	0	M. Arago.
	52	45	M. Malus.

From which it follows, that the three first observations approach much nearer to the general law than that of Malus assumed in the table. The following observations give additional evidence to the law, if it were required.

Diamond . . .	67°	13	M. Arago.
Diamond . . .	67	0	M. Biot.
Topaz . . .	59	0	M. Arago.
Sulphate of Barytes .	57	47½	M. Biot.
Sulphate of Barytes .	58	0	M. Arago.
Sulphate of Barytes .	58	29[*]	Dr. Brewster.
Native Hydrate of Magnesia,	57	25	Dr. Brewster.

It is of great importance to remark, that the total amount of errors in the seventeen observations in the table, is only 259′, which gives an average error of 15′. In general, the observed angles are *less* than the calculated angles, the sum of the *negative* being to the sum of the positive errors, as 174′ to 85′. This result is very easily explained, for, in using white light, we obtain a mean result corresponding to the *most luminous* rays which have a less index of refraction than the *mean rays of the spectrum*, and therefore all the observed angles ought to be increased by a small quantity corresponding to this difference.

Prop. VI.

When a pencil of light is polarised by reflexion, the sum of the angles of incidence and refraction is a right angle.

Let MN, Fig. 21. be the reflecting surface, and BA, a ray of light polarised by reflexion in the direction AD, and let AC be the refracted ray. Then, since EF, the tangent of the polarising angle BAE, is equal to m, or the index of refraction, we have, by the law of the sines, $CL = \frac{BG}{m} = \frac{BG}{EF}$. But from the similar triangles ABH, AEF, we have AH or BG : HB :: EF : Rad.; and $HB = \frac{BG}{EF}$, consequently $CL = HB$ and the angle $BAN = CAK$. But $EAB + BAN = 90°$, hence $EAB + CAK = 90°$.

Cor. The complement of the polarising angle is equal to the angle of refraction.

Prop. VII.

When a ray of light is polarised by reflexion, the reflected ray forms a right angle with the refracted ray.

Since the angles DAM, BAN, CAK, are equal to one another, the angle DAC is equal to the right angle MAK: hence the reflected ray AD forms a right angle with the refracted ray AC.

Prop. VIII.

When a pencil of light is incident on the second surface of transparent bodies, at an angle whose co-tangent is equal to the index of refraction, the reflected portion will be either wholly polarised, or the quantity of polarised light which it contains will be a maximum.

As the images formed by the first and second surfaces of a transparent plate are simultaneously polarised, this proposition is established by the experimental results in the preceding table.

Prop. IX.

The angle of polarisation at the second surface of transparent bodies, is the complement of the angle of polarisation at the first surface.

As the angle of incidence at the second surface is equal to the angle of refraction at the first surface, and as this latter angle is, by the corollary to Prop. VI. equal to the complement of the angle of polarisation, it follows, that the two polarising angles are complementary to each other.

Prop. X.

When a ray of light is polarised by reflexion from the second surface of transparent bodies, the reflected ray will form a right angle with the refracted ray.

Let AB, Fig. 22. be a ray incident at the first surface MN, AD the ray polarised at that surface, AC the ray incident at the second surface PQ, and CM the ray polarised at that surface; then, if CF be the refracted ray, the angle MCF is a right angle. By Prop. VII. DAC is a right angle, and on account of the parallelism of MN, PC, and BA, CF, the angle FCP is equal to DAM, but MCP is equal to MAC, hence the whole MCF is equal to the whole DAC, or a right angle.

Cor. 1. The ray CM, reflected by the second surface, is at right angles to the ray AB incident on the first surface.

Cor. 2. The internal reflected ray CM forms with the external reflected ray AD, an angle equal to the angle of deviation CAO.

Cor. 3. The ray CF, emerging from the second surface, forms with the first reflected ray, AD, an angle equal to the complement of the angle of deviation.

Prop. XI.

When a pencil of light is incident upon the separating surface of two media having different indices of refrac-into mm', it will be polarised at an angle whose tangent is equal to the quotient of the greater index of refraction divided by the lesser, or $\frac{m}{m'}$, if m exceeds m'.

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[*] Mean of four observations, all of which were above 58° 19′.

This proposition is a necessary consequence of the general law, and is also deduced from direct experiment.

If we call A the angle whose tangent is equal to $\frac{m}{m'}$, then the corresponding angle at which the pencil is incident from air upon the first surface of the upper medium, or $\alpha = \text{sin. A} \times m$.

In the case of *water* and *glass*, where m is equal to 1.525, and m' to 1.336, we have the polarising angle at the surface of separation, or $A = 48° \; 47'$, and $\text{sin. A} \times m' = 1.0048$, consequently α is greater than 90°. Hence it follows, that when a ray of light is incident upon a parallel plate of water lying upon a plate of glass, there is no angle of incidence upon the first surface of the water at which the ray will suffer polarisation at the separating surface of the two media. The polarisation of the incident pencil increases from 0° to 90°, and is nearly complete at 90°.

When m is equal to 1.508, which is sometimes the case, then $\text{sin. A} \times m' = 1.000$, and $\alpha = 90°$ exactly.

This conclusion was so unexpected, that Dr. Brewster immediately endeavoured to confirm it by experiment. The result was exactly conformable to the law: the polarisation of the pencil became more and more perfect from 0° to 90° of incidence. Between 80° and 90° the change was scarcely perceptible, owing to the slow variation of the sines, for when the pencil is incident at 80°, the angle of incidence at the separating surface is 47° 29′, while at an incidence of 90° it is no more than 48° 28′, differing only 59′ from the other.

PROP. XII.

When light is polarised at the separating surface of two media, the sum of the angles of incidence and refraction is a right angle, and the reflected ray forms a right angle with the refracted ray.

This proposition is demonstrated in the same manner as Prop. VI. and VII. the separating surface producing always the same phenomena as the first surface of any body, whose index of refraction is equal to the quotient of the indices of refraction for the two contiguous bodies.

PROP. XIII.

When a ray of light is incident at any angle except a right angle upon the surface of a transparent body, a certain portion of the reflected light is completely polarised, while the remaining portion has suffered a physical change, or has acquired, in various degrees, a character approaching to complete polarisation.

This proposition has been established by direct experiments made with glass, whose polarising angle is 56° 45′.

If a pencil of light is reflected from glass at an angle of 62° 30′, or 50° 20′, *i. e.* either above or below the polarising angle, the portion of light which is not completely polarised, has so far received this character, that it will be completely polarised by a second reflexion at the same angle, whereas, had it been absolutely unpolarised light, it could not have been polarised at any angle different from 56° 45′, the real angle of polarisation

In like manner, *three* reflexions at an angle of 65° 35′ or 46° 30′, or *four* reflexions at an angle of 67° 33′, or 43° 51′, will polarise the whole pencil, while at angles above 82° or below 18° more than 100 reflexions are necessary to produce complete polarisation.

PROP. XIV.

If a ray of light is partly polarised by reflexion at any angle, it will be more and more polarised by every successive reflexion in the same plane, till its polarisation is complete, whether the reflexions are made at angles all above or all below the polarising angle, or at angles, some of which are above and some below the polarising angle.

This proposition is deduced from numerous experiments which may be easily repeated. It is extremely difficult, however, on account of the rapid attenuation of the light when it has undergone a few reflexions from glass, to determine satisfactorily the relation between the number of reflexions and the angles of incidence at which they polarise a pencil of light. The experiments which Dr. Brewster has made are represented by the following law; A, a, being the angles of incidence above and below the polarising angle, m the index of refraction, and N n the number of reflexions above or below the polarising angle.

$$\text{Tang. A} = m \times \sqrt[3]{N}$$

when the angle of incidence is *greater* than the polarising angle for one reflexion, and

$$\text{Tang. } a = \frac{m}{\sqrt{n}}$$

when the angle of incidence is less than the polarising angle for one reflexion. Hence we have

$$N = \left(\frac{\text{tang. A}}{m}\right)^3 \text{ and}$$

$$n = \left(\frac{m}{\text{tang. } a}\right)^3$$

PROP. XV.

If a pencil of white light is incident at the maximum polarising angle upon any transparent body whatever, a portion of the reflected pencil, consisting of the mean refrangible rays, will be completely polarised, while another portion of the beam, consisting of the blue and red rays, will not be completely polarised, and will therefore not vanish when the image from which the light proceeds is examined with a prism of calcareous spar.

It is obvious from Prop. V. that all the rays which compose a beam of white light cannot be polarised at the same angle of incidence. When the pencil is incident at the maximum polarising angle, or at an angle whose tangent is equal to the index of refraction for the mean refrangible rays, these rays alone will be polarised. Neither the *red* rays, which are incident at an angle above their polarising angle, nor the blue rays, which are incident at an angle below their polarising angle, will be completely polarised; and when the reflected pencil which contains them is viewed through a doubly refracting crystal, the *mean* refrangible rays will vanish, while the *red* and *blue* rays will compose a beam nearly white, and will not vanish, in consequence of its not being completely polarised.

Prop. XVI.

If a pencil of HOMOGENEOUS or coloured light is incident upon any transparent body at an angle whose tangent is equal to the index of its refraction, every ray of the reflected pencil will be completely polarised in the plane of reflexion.

This proposition is a necessary consequence of those which precede it; and has also been established by direct experiments upon diamond and realgar.

There is one result of the preceding inquiry which is entitled to our notice, and to which we have already alluded in our account of the theory of reflexion. As the incident rays do not enter the reflecting surface, and as there is no reason to believe that that surface has any power of communicating polarity to the light which falls upon it, the polarisation of the reflected ray can only be ascribed to the change of direction produced by the reflecting force. Hence Dr. Brewster concluded that the refracting force extends beyond the reflecting force, as explained in the following propositions.

Prop. XVII.

If light were polarised simply by the action of the reflecting force, the polarising angle would be 45°.

For when the refracting force is infinitely small, the polarising angle is 45°. The reflecting force is also infinitely small in this case, but any diminution of the reflecting force, however great, does not alter the direction of the reflected ray with respect to the incident ray, or the position of any point or side of a ray with regard to the direction of its motion. It may also be remarked, that 45° is the only angle of reflexion at which any point or side of a ray makes a revolution of 90° relative to the direction of its motion. See Prop. XIX. and Cor. 2. of the same proposition.

Prop. XVIII.

Every ray of light polarised by reflexion has been acted upon by the refracting force before it has suffered reflexion.

This follows from the light not being polarised at 45°, but at various angles, increasing with the refractive force.

Cor. It results from this proposition, that light suffers a partial refraction before it is reflected; and that the refractive force extends to a greater distance than the reflecting force from the surface of transparent bodies. This result is not only consistent with the most extensive analogies, but affords an explanation of phenomena which have hitherto been unexplained.

Prop. XIX.

When a ray of light is incident at the polarising angle upon any substance whatever, it receives such a change in its direction, by the action of the refracting force, that the real angle of incidence at which it is reflected and polarised is 45°.

Let MN, Fig. 23 be the refracting and the reflecting surface, and OP the termination of the sphere of refracting activity. Let a ray RG be incident at G, at the polarising angle, and let it be refracted into the line GB, before it is reflected from the surface MN.* A part of the ray GB will penetrate the surface MN, and be refracted into the line BF, while another part will be reflected in the direction BA, and again refracted at A into the line AS. Continue SA to C, and FB to D. Then, since half of the refraction is supposed to be performed before the ray reaches B, and half of it after it penetrates the medium MN, we have BAC = DBC = half the angle of deviation. But by Prop. VII. ADB is a right angle; hence ABC is also a right angle, and the angles ABE, GBE, each half a right angle, or 45°.

Cor. 1. At the instant of reflexion, when the refraction at B commences, the refracted ray sets off at right angles to the reflected portion.

Cor. 2. The *real angle of polarisation* is 45°, the effect of the refractive force being merely to bend the ray of light so as to make it suffer reflexion at this particular angle.

Cor. 3. The excess of the angle formed by the incident and the polarised ray, above a right angle, is equal to the angle of deviation. The angle PAB, Fig. 3. which is equal to the angle of deviation OAC, is obviously the excess of DAB above the right angle DAP.

Scholium.

The preceding investigations respecting the polarisation of light by reflexion, from Prop. V. to Prop. XIX. were given by Dr. Brewster, in the *Philosophical Transactions* for 1816, to which we must refer the reader for a more detailed account. The polarisation of light by metallic surfaces, and by the surfaces of transparent bodies, when they produce total reflexion, will be treated of in subsequent sections.

Sect. III.—*On the Polarisation of Light by Refraction.*

Although the polarisation of light by refraction had escaped the notice of Malus, in his early experiments, yet he was led, in the prosecution of them, to the discovery of this curious fact, in the year 1811. Some time after this, M. Biot made the same discovery, and, in the summer of 1813, Dr. Brewster, ignorant of what had been done abroad, discovered the same fact, and succeeded in determining also the law of the phenomena. Malus and Dr. Brewster were led to the discovery of this property by entirely different methods. The former observed it in an examination of the light transmitted by uncrystallized plates, and the latter by the *polarisation in one plane* of the light transmitted by a piece of mica, whose laminæ must have been partially detached, the mica having absorbed or reflected all the light of one of its images From this remarkable fact, Dr. Brewster was led to try a number of thin plates of glass, which he found to polarise the transmitted light in one plane exactly like the piece of mica.

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* In order to keep the figure from being complicated, we have supposed the reflexion to take place all at once when the ray reaches the surface MN. The demonstration would have been exactly the same if the ray had been represented as suffering a gradual reflexion in passing through the sphere of reflecting activity.

Prop. XX.

When a ray of light is incident at the polarising angle on a plate of glass, a portion of the refracted pencil nearly equal to the reflected pencil is polarised in an opposite manner to the reflected pencil.

Let BA, Fig. 21. Plate CCCCXXXV. be the ray incident at the polarising angle, and AD the pencil polarised by reflexion; then the refracted pencil AC will contain a portion of light polarised in an opposite manner to AD. If AD falls upon a second refracting surface, another portion of it will be polarised by reflexion from that surface, and a similar portion by refraction, so that the transmitted ray contains now a greater quantity of polarised light. In like manner, by transmitting the light through a bundle or pile of glass plates, such as ABCD, Fig. 1. the transmitted ray will always contain more and more polarised light, till the resulting pencil E'E is wholly polarised in one plane.

If the ray ST, Fig. 20. is polarised by a bundle of glass plates, parallel to AB, and acting upon a ray RS transmitted through them, it will be found that, before it is received upon the second plate CD, it will entirely penetrate the plate in the azimuths 0° and 180°, and will be reflected like common light in the azimuths 90° and 270°, which is exactly the reverse of what took place when the ray ST was polarised by reflexion from AB.

The operation of bundles of glass plates will be still more strikingly seen by referring to Fig. 2 where AB is a bundle of glass plates, receiving the incident ray RS at the polarising angle, so as to polarise the transmitted ray ST. Then, if a second and similar bundle CD receives the polarised ray ST, so that the plane of refraction in CD is parallel to the plane of refraction in AB; in this case the light will be *wholly transmitted* through the second bundle CD, as the ray ST falls upon the reflecting planes of CD, under the same circumstances as it did in Fig. 1. when no light was reflected. The same effect will be produced at an azimuth of 180°, by turning the bundle CD round the ray ST, so as to preserve the same inclination to it. At the azimuths of 90° and 270°, on the contrary, it will be wholly reflected at its various incidences upon the plates, and not a single ray will be transmitted through the bundle.

From the various observations made by Malus, he deduces the following general conclusion.

"When a ray of light falls upon a plate of glass at an angle of 35° 25′, all the light which it reflects is polarised in one direction. The light which traverses the glass is composed, 1st. of a quantity of light polarised in a direction opposite to that which is reflected, and proportional to it; and, 2dly, *of another portion, not modified, and which preserves the character of direct light*."*

In his paper on the polarisation of light by oblique transmission, Dr. Brewster has given an account of experiments analogous to those of Malus,† and he obtained the same phenomena with the thinnest *films of glass;* with the elementary *films of mica*, with thick *plates of mica*,‡ with folds of *gold-beaters' skin*, and with the films of *gold leaf*.

In order to determine the law of the phenomena, as depending on the number of refracting plates, and the angle of incidence, he made numerous experiments, the results of which are contained in the following proposition.

Prop. XXI.

The number of plates which polarise a maximum of light by transmission at different angles of incidence are to one another as the co-tangents of the angles of incidence.

For the purpose of determining the law stated in the proposition, Dr. Brewster provided himself with forty-seven plates of crown-glass, each of which was about three inches long and one broad, and having formed them successively into parcels of 47, 44, 41, 39, &c. down to eight plates, he measured by means of a theodolite the different angles at which a pencil of light was polarised when transmitted through these various parcels. The results which were thus obtained are given in the following Table.

Table showing the angles at which Light is polarised by oblique Refraction through different numbers of Plates.

Number of plates in each parcel.	Angles of incidence at which light is polarised.	Angles of incidence at which light is polarised.	Differences between the calculated and observed angles.
	By calculation.	By experiment.	
8	79° 11′	78° 52′*	0 19′ —
10	76 33	76 24	0 9 —
12	74 0	74 2	0 2 +
14	71 30	72 15	0 45 +
16	69 4	69 40	0 36 +
18	66 43	66 43	0 0
21	63 21	63 39	0 18 +
24	60 8	61 0	0 52 +
27	57 10	56 58	0 12 —
29	55 16	54 50	0 26 —
31	53 28	53 16	0 12 —
33	51 44	51 0	0 44 —
35	50 5	50 23	0 18 +
39	47 1	46 50	0 11 —
41	45 35	45 49	0 14 +
44	43 34	44 0	0 26 +
47	41 41	42 0	0 19 +
100	22 42		
200	11 49		
500	4 47		
1,000	2 24		
2,000	1 12		
4,000	0 36		
14,000	0 1		
8,640,000	0 0 1″		

* This result was obtained by a parcel of plates of parallel glass.

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* *Bulletin de la Soc. Phil* June, 1811, p. 299

† *Phil. Trans.* 1814.

‡ "A plate of *mica*, 0.127 of an inch thick, polarised the light at an angle of 63°, while a plate 0.093, polarised it wholly at an angle of 71° 45′."

Upon comparing the number of plates with the angles, it was obvious that the number of plates were always to one another as the co-tangents of the angles of incidence at which they polarised the transmitted light; that is, if n, n', represent the number of plates in any two parcels, and ϕ, ϕ', the angles at which the pencil was polarised, we have

$$n : n' = \text{cotang.}\,\phi : \text{cotang.}\,\phi' \text{ and}$$
$$n \times \text{tang.}\,\phi = n' \times \text{tang.}\,\phi'.$$

Hence it follows, that the *number of plates in any parcel multiplied by the tangent of the angle at which it polarises light is a constant quantity.* From a great number of observations, made with a parcel of eighteen plates, Dr. Brewster found the constant quantity for crown glass to be 41.84, when the light was that of a good wax candle, placed at the distance of about 12 feet, so that we have

$$\text{tang.}\,\phi = \frac{41.84}{n}$$

that is, divide the constant quantity by any given number of plates, and the quotient will be the natural tangent of the angle at which that number will polarise a pencil of light.

In this way Dr. Brewster computed the *second* column of the Table, which differs very little from the observed column.

Prop. XXII.

When a pencil of light is incident at any angle except a right angle, upon the surface of a transparent body, a certain portion of the transmitted light is completely polarised, while the remaining portion has *suffered a physical change*, approaching more or less to that of complete polarisation.

This proposition, which Dr. Brewster proved to be true with regard to the reflected pencil, is true also of the transmitted pencil. It appears, from the Table, that 24 plates are necessary to polarise completely a given pencil of light, at an angle of 61°, consequently 12 plates will not polarise the whole pencil at the same angle. Let us now suppose that the portion not polarised by the 12 plates amounts to 20 rays out of 100; then, if these 20 rays were *absolutely unpolarised, and in the same state as direct light*, they would require to pass through 24 plates at an angle of 61°, in order to be completely polarised. But the experiments prove that they require to pass only through other 12 plates at that angle, in order to be completely polarised. It therefore follows, that the 20 rays have been *half polarised* by the first 12 plates, and the polarisation completed by the other 12. Hence arises the mistake of Malus, who observes, that the light transmitted obliquely through glass, consists, 1st. of a quantity of polarised light; and 2d, *of another portion, not modified, and which preserves the characters of direct light.*[*]

Prop. XXIII.

If a pencil of light is *partly polarised* by transmission at any angle, it will be more and more polarised at every successive transmission in the same plane till its polarisation is complete, whether the transmissions are made at angles all above or all below the polarising angle, or at angles, some of which are above, and some below the polarising angle.

The truth in this proposition is deduced from numerous experiments, besides those which are given in the preceding Table, and may be easily verified.

Prop. XXIV.

When a pencil of light is transmitted through one or more parallel plates of the same refractive power, the quantity of light polarised by transmission will be a maximum when the tangent of the angle of incidence is equal to the index of refraction.

The quantity of light polarised by reflexion is then a maximum, by Prop. V. p 181, and consequently the quantity polarised by transmission, which is equal to it, must also be a maximum.

Cor. When the plates have different refractive powers, they must be inclined to one another at such angles, that the pencil may fall upon each of them at an angle whose tangent is equal to its own index of refraction.

Prop. XXV.

When a pencil of light is transmitted through a number of parallel plates of glass, whose index of refraction is m, separated by a fluid whose index of refraction is m', the quantity of polarised light will be a maximum when the tangent of the angle of incidence is equal to $\frac{m}{m'}$, if m exceeds m'.

This proposition is deduced from Prop. XI. p. 716. and Prop. XXIV.

Prop. XXVI.

If a pencil of light is incident upon a number of uncrystallized plates, or parcels of plates, each plate, or each parcel of plates, being inclined at different angles, but having all their surfaces at right angles to the plane of refraction, the total polarisation of the pencil will commence when the sum of the products of the tangents of the angles of incidence, and the number of plates in each parcel, are equal to the constant quantity due to the refractive power of the plates, and the intensity of the incident pencil.

Let n, n', n'' represent the number of plates in each pencil, a, a', a'' the angles of incidence, and A the angle at which the pencil would begin to be wholly polarised by transmission by all the plates put together and parallel, and C the constant quantity; then the total polarisation will commence when $n\,(\text{tang.}\,a) + n'\,(\text{tang.}\,a') + n''\,(\text{tang.}\,a'') = n + n' + n''\,(\text{tang.}\,A) = C = 41.84$ in crown glass, when the light of a wax candle, at the distance of 10 feet, is used.

Prop. XXVII.

When a pencil of light is incident on a transparent uncrystallized plate, the *transmitted* rays contain two portions of light, one of which is polarised in the plane of refraction, and the other is a plane perpendicular to it.

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[*] M. Biot repeats the same opinion, "la portion de lumiere transmise qui conserve les characteres de la lumiere directe." *Traité de Physique*, tom. iv. p. 296; and *Precis*, &c. 1821, tom. ii. p. 504.

The light polarised in a plane perpendicular to the plane of refraction, is that which is polarised by transmission, as already explained; and is a portion of the pencil S *a* T, Fig. 3. proceeding from the incident ray RS. The light polarised in the plane of refraction are rays *c* V, *e* W, produced by the light which has suffered reflexion at the points *a*, *b*, *c*, *d*. This portion of light increases with the obliquity of incidence; and since it may be considered as producing a portion of direct light when combined with a portion of the polarised light in the pencil *a* T, it becomes impossible to polarise the light transmitted through two, three, or four plates of glass, however great be the angle of incidence. See *Edinburgh Transactions*, vol. viii. p. 27.

SECT. IV. *On the Colours produced by transmitting Polarised Light through thin Crystallized Plates, or near the resultant axes of Doubly Refracting Crystals.*

In the year 1811, the colours of thin crystallized plates were discovered by M. Arago, and the same discovery was made by Dr. Brewster, and in 1812* communicated to the Royal Society of Edinburgh, before he or any of his countrymen had any knowledge of what had been done in France. But though the general fact which each of these authors discovered was the same, yet Dr. Brewster was led, by a peculiar mode of observation, to examine the phenomena seen along the real and the resultant axes of crystals, and was thus led to the discovery of the single and double systems of coloured rings, which had escaped the observation of others, and which have led to those general laws of polarisation and double refraction, which could never have been deduced from the examination of crystallized laminæ.

Before we begin to explain this class of phenomena, we shall describe the method by which they may be most easily observed.

Let RS, Fig. 4. be a ray of direct light, from the sky or from a candle, and ST the pencil polarised by reflexion from the plate of glass AB; then, as we have before seen, the ray ST will not suffer reflexion, if it is incident at the polarising angle upon a second plate CD, provided the plane of the second reflexion is at right angles to that of the first, passing through RST, which is called the *Plane of Primitive Polarisation.* Let the two plates of glass, therefore, be capable of being fixed in this position, so that the light is reflected in the direction TV, which will be known by the appearance of an undefined dark spot on the image of the part of the sky which is reflected from AB. The plate AB may be called the *polarising plate*, and CD the *analyzing plate.*

If we now take a thin plate of *sulphate of lime or gypsum*, sliced from a crystal by means of a lancet or pen-knife, such as *e f*, and expose it to polarised light by holding it in the reflected ray ST, it will be found by turning it round in a plane, perpendicular to ST, and looking into the plate CD, in the direction VT, that there are four positions, distant 90° from each other, viz. 0°, 90°, 180°, and 270°, where no change is produced; while at every intermediate position, the surface of the plate of sulphate of lime will appear covered with a brilliant colour, supposed *red.* The intensity of this colour is a *maximum* at the points 45°, 135°, 225°, 315°, and it appears entirely at 0°, 90°, 180°, and 270°.

Let the analyzing plate be now gradually turned from the position in Fig. 8. in the azimuth of 90°, to the position in Fig. 1. or the azimuth of 0°, which we shall call the zero of the circle in which it revolves round the polarised ray ST, the plate of sulphate of lime *e f* remaining fixed in the azimuth of 45°, so as to give the brightest *red;* then, by looking into the analyzing plate CD, it will be seen that the red gradually becomes fainter and fainter, till CD comes into the azimuth of 45°, when no colour whatever appears. Beyond this point, or 45°, a faint *green* appears, which gradually becomes more and more intense, and reaches its maximum at 90°. From 90° the *green* becomes paler, till it entirely disappears at the azimuth of 135°, when the *red* again commences, and reaches its maximum of brilliancy at 180°. The very same changes are repeated from 180° to 360°, or 0°.

In studying these simple facts, it is manifest that the plate *e f* transmits two sets of differently coloured rays, viz. *red* and *green*, which are the Extraordinary and the Ordinary, which we shall call E and O, and which are always complementary to each other, or together make white light. Its colour is always *red* when the analyzing plate CD is in the azimuth of 90° and 270°, and always *green* when CD is in the azimuth of 0° and 180°.

Now, as none of the *green* rays O are reflected in the azimuth of 90°, it is quite clear that they are polarised in the same manner, or in the same direction or plane, as the ray of white light ST, none of which is reflected from CD in that azimuth; that is, the green rays O *preserve their primitive polarisation*, or are not acted upon by the plate *e f*. In like manner, it is manifest, that as the *red* rays E are reflected, they must have a polarisation different from that of ST, or these rays must have had *their polarisation altered by the plate e f*. When *e f* was in the azimuth of 45°, the red rays were most copiously reflected when CD was in the azimuth of 90° and 180°, and not reflected at all in the azimuth of 0° and 270°. Hence they must in this case have been polarised in a plane at right angles to the polarisation of ST, that is, their polarisation must have suffered a change of $90^\circ = 2\times45^\circ = 2a$, calling *a* the azimuth of the plates *e f*.

In order to determine if the change of polarisation in the tint E is equal to 2 *a* in every other azimuth, let the plate CD, or the plane of reflexion from it, be placed in an azimuth equal to *a*, the azimuth of the crystalline plate; then, if the pencil E is polarised in the azimuth 2 *a*, the plane of reflexion from the plate CD will form equal angles, viz. *a*, with the plane RSP, in which the pencil O is polarised, and the new plane in which E is supposed to be polarised, and consequently it will reflect an equal portion of these two kinds of rays, that is, of the *red* and *green*, so that the resulting pencil will be white. By making this experiment at all azimuths, or for all values of *a*, M. Biot found this to be the case, and hence he established his doctrine of moveable polarisation in a double azimuth.

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* *Treatise on New Philosophical Instruments*, Preface, p. xiii. and p. 336.

By applying to the two tints O and E, the formulæ of Malus for the division of the rays in the rhomboid, M. Biot found that the colour and intensity of the reflected pencil was represented by the following formulæ:

$$PO = O\ \text{Cos.}^2\ \alpha + E\ \text{Cos.}^2\ (2a - \alpha);$$

a representing the azimuth of the plate *ef*, and α the azimuth of the analyzing plate CD. In order to determine the intensity of the tint when only E is visible, let the plate CD be put into the azimuth of 90°, in which case E only is reflected, and O wholly transmitted. Then $\alpha = 90°$, and the above formula becomes

$$P\,o = E,\ \text{Sin.}^2\ 2a.$$

In every other position, the reflected ray will be a combination of the tints O and E in different proportions given by the formula. The reflected ray will always be white when $a = 0°;\ 90°;\ 180°;\ 270°$; or $a = \alpha$; $\alpha + 180°$; or $\alpha + 270°$.

If, instead of analyzing the light transmitted through the plate *ef* by reflexion from CD, we analyze it with a rhomboid or a prism of Iceland spar, the principal section of which is supposed to replace the plane of reflexion from CD; then M. Biot has shown that the phenomena are represented by the formulæ,

$$P\,o = O\ \text{Cos.}^2\ \alpha + E\ \text{Cos.}^2\ (\alpha - 2a)$$
$$P\,e = O\ \text{Sin.}^2\ \alpha + E\ \text{Sin.}^2\ (\alpha - 2a)$$

α now representing the angle which the principal section of the rhomboid makes with the plane RST, or that of primitive polarisation. When the principal section is in the plane RST, then $\alpha = O$ and we have

$$P\,o = O + E\ \text{Cos.}^2\ 2a.$$
$$P\,e = E\ \text{Sin.}^2\ a.$$

Having thus determined the rule of the tints, M. Biot next proceeds to examine their nature, and their relation to the thickness of the plates *ef*.

By using slices of sulphate of lime of various thicknesses, he concludes that the tints E are *identically* the same with those in Newton's table or scale, which we have given in page 696; and that they vary with the thickness of the plate according to the values of the tints calculated for glass, which has nearly the same refractive power as sulphate of lime. By taking very accurate measurements of different plates with the Spherometer, he obtained the following results when the light was transmitted perpendicularly through the plates.

	Millimetres.
Thickness at which no tint is produced, or the commencement of black in Newton's table	0.011777
White of the first order - - - -	0.31144
White composed of a mixture of all the colours - - - - - - -	0.45493

Having determined the position of the axis of sulphate of lime, which lies in the plane of the laminæ, and makes an angle of 16° 13′, with one of the sides of the oblique parallelograms, into which the laminæ are divisible by cleavage, he placed two plates with *their axes coincident*, and found that they produced a tint equal to that which would have been produced by a plate equal to their united thickness; but if the axes of the two plates were *at right angles to one another*, the tint produced was the same as that of a plate whose thickness was equal to their difference. Hence two plates of equal thickness, with their axes crossed, gave no tint at all, and by using plates of considerable thickness, and which gave no tints separately, he could produce the polarised colours, provided the difference in the thickness of the plates did not exceed 0.45493 of a millimetre, the thickness at which the coloured rings terminate.

M. Biot made analogous experiments on calcareous spar and other minerals, and obtained the results in the following table.

	Intensity of Polarising Force.	Nature of the Action.
Calcareous spar	17.750	Repulsive
Sulphate of barytes	1.250	Attractive
Sulphate of strontian	1.070	Undetermined
Sulphate of lime	1.000	Attractive
Rock crystal	1.000	Attractive
Beryl	0.523	Repulsive

The numbers in the preceding table, are in the inverse ratio of the thicknesses that produce an equilibrium of action. Thus, if a plate of beryl has its axis crossing the axis of a plate of carbonate of lime, then the two tints will destroy one another, if their thicknesses are as 0.523 to 17.75; that is, a plate of carbonate of lime, whose thickness is 0.523, will produce the same tint as a plate of beryl, whose thickness is 17.75.

The effect of the combination of plates which we have mentioned, takes place only when a *repulsive* is combined with a *repulsive* crystal, or an *attractive* with an *attractive* crystal, and they are reversed when a *repulsive* is combined with an *attractive* crystal. If, for example, we combine a plate of *rock crystal* and *beryl*, so as to have their axes *coincident*, the tint will be equal to that produced by the difference of their united action, and if the tints are of the same value, they will destroy one another; whereas, if their axes are crossed at right angles, we shall obtain a tint equal to the sum of their actions. In all these combinations, it is supposed that the plate is cut so as to have its axis lying in the plane of its faces.

In comparing the tints of sulphate of lime with those of the coloured rings of Newton, as formed between two object glasses, and examining the effect of combining plates of different thicknesses, Dr. Brewster employed a different method from that of M. Biot. He took a uniform plate of sulphate of lime, about $\frac{1}{23}$th of an inch thick, and ground down one of its faces so as to make the thickness vary from $\frac{1}{25}$th of an inch down to the thinnest possible edge. He then placed the plate in water, which, by a partial dissolution, made it thinner at the edges, and gave its surface a sufficient polish. By exposing this plate to polarised light, a series of rectilineal coloured fringes were seen, parallel to the common section of its inclined surfaces, showing at one view the nature of the tints, from the black, at the beginning of the scale, up to the compound white, where all the colours were mixed, and the way in which they varied as the thickness of the plate increased. He then cut this plate into two, and by combining them in different ways, he saw at once all the different effects of the combination of plates of various thicknesses. When the plates were crossed at right angles, as shown in Fig. 5. a new set of fringes was produced parallel to the black fringe CD, arising from the opposite action, or equilibrium of all the similar tints.

The next object of M. Biot was to determine the manner in which the tints varied when the polarised ray was transmitted at different inclinations to the axis. From various experiments on *Rock crystal*, *Calcareous spar*, *Arragonite*, and *Sulphate of lime*, he concluded, that if the maximum tint of the crystal, or the tint perpendicular to the axis, was represented by 1, then Sin.$^2\varphi$, (φ being the inclination of the ray to the axis,) would represent the tint at all the other inclinations. This deduction, however, was quite premature, and inconsistent with the very experiments on which it seemed to be founded. Whenever the law was contradicted by experiment, M. Biot ascribed the discrepancy to *secondary forces:* and those very experiments which actually overturned the law, were held as affording it support. In *Rock crystal*, M. Biot found the tints to be represented by Sin.$^2\varphi$ with tolerable accuracy; but as he considered the secondary forces in rock crystal as modifying the principal force, at least to a certain distance from the axis, the law of Sin.$^2\varphi$ could not be established by these observations.

His experiments on *Arragonite*, also, give Sin.$^2\phi$, although this crystal has *two axes*, and cannot have its tints regulated by such a law. His experiments on *Calcareous spar* were better fitted to establish the law of Sin.$^2\varphi$; but when we consider that his mode of observation was such as to lead to such errors in arragonite, it was also insufficient to establish the law in calcareous spar, or any other crystal.

The principal experiments of M. Biot, however, were made with *Sulphate of lime*, from its being peculiarly favourable for that class of experiments. He measured the tints in planes, forming angles of 0°, 22½°, 45°, 67½°, and 90° with the axis, and at all incidences upon the laminæ up to 78°. When these results were compared with those found by Sin.$^2\varphi$, the discrepancy was enormous; but, instead of abandoning this hypothesis, he ascribed all these irregularities to the influence of imperfect crystallization, and represented the tints by complicated empirical formulæ, involving the 6th power of the cosine of the inclination of the ray to the axis, and the 5th power of the sine of the angle of refraction.[*]

Notwithstanding that these results were absolutely irreconcilable to any law, M. Biot concludes, that, with the exception of mica, which has *two axes of polarisation*, all other crystals have only one axis of double refraction, from which the polarising force emanates; that all crystals are divisible into two classes, viz. *attractive* and *repulsive;* and that the laws investigated for sulphate of lime are the general laws of polarisation for all other crystals[†] The following were the crystals examined by M. Biot.

Calcareous spar. Tourmaline. Sulphate of lime.
Rock crystal. Felspar. Sulphate of barytes.
Beryl. Arragonite. Sulphate of strontian.
Phosphate of lime. [‡] Topaz. Mica.

In the preceding pages, we have endeavoured to give a brief account of the state of the subject of polarisation and double refraction in regular crystals, after the publication of M. Biot's *Traité de Physique* in 1816.

M. Malus, in his *Theorié de la Double Refraction*, p. 246, &c. concluded from his elaborate experiments, that *Arragonite* and *Sulphate of Barytes* have one axis of double refraction, like quartz and calcareous spar.

For some years before M. Biot published his *Traité de Physique*, it was well known that *Topaz* and *Mica* had two axes of polarisation; but it was never even conjectured that the separation of the two images vanished in the lines where the polarisation was nothing. Such a conclusion, indeed, could not be obtained by the methods of observation which were then in use; and it was not till the discovery of the system of coloured rings by Dr. Brewster, that the general law of polarisition and double refraction could be investigated with any degree of success. The history of this investigation we shall now proceed to detail.

In the beginning of the year 1813, when Dr. Brewster was examining the coloured tints which he had discovered by transmitting polarised light through various crystallized bodies, he adopted the method of holding the crystallized plate as near the analyzing plate CD, Fig. 20. as possible, or in contact with the prism of Iceland spar, when it was substituted in place of the plate. By this means he was enabled to see at one view the effect produced by polarised light incident at various angles on the plate; and in applying this method to topaz, he discovered its double system of rings, which could not possibly be seen by any other method.

Having taken a plate AB, Fig. 6. of the blue *Topaz* of Aberdeenshire belonging to Mr. Allan, and possessing the finest natural cleavage planes perpendicular to the axis of the primitive prism, he transmitted through it obliquely a polarised pencil ST, forming an angle STW of 60° 38′ with the perpendicular TW; and upon analyzing the light TV with a reflecting plane like CD, Fig. 4 he was surprised by the sight of a system of brilliant elliptical rings, as shown in Fig. 7. By turning the plate CD from its azimuth of 90° to 180°, each colour underwent the same change, as already described to take place with a single tint of sulphate of lime; and when CD was in azimuth 180°, a set of rings exactly complementary to the first set were now visible, the two sets being related to one another in the same way as the rings of thin plates seem by reflexion and transmission. By turning round AB, so that the polarised light ST fell upon the plate AB in another direction S′TV, inclined at an angle S′TW of 60° 38′, another system of elliptical rings was also seen of the very same form and character. Hence it appeared that topaz had two axes of polarisation, viz. STV, S′TV′, inclined to one another at an angle of about 65°.[*] Dr. Brewster has described at great length various new phenomena, produced by a variation in the circumstances under which the rings were produced; and he has given a detailed Table of the colours of the rings observed in ten different azimuths passing through their centre. From this Table, and from the coloured drawings of the rings, sent to the Royal Society in 1813, it appears that the colours are not uniformly those of Newton's scale; that the black does not commence at the centres of the rings, but at one side of them; and that the colours of the inner ends of the rings are different from the colours of the outer ends

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[*] The formula given by M. Biot is $E' = E\left(\frac{\text{Sin.}^2\,U + 0.0713653\ \text{Cos.}^6\,U}{\text{Cos.}\,u}\right)$ and $\text{Sin.}\,u = a\ \text{Sin.}\,\theta' + b\ \text{Sin}^5\,\theta'$; E′ being the tint at the angle U, E the tint at a perpendicular incidence, θ' the angle of refraction, and a and b two co-efficients determined by experiment.

[†] "Toutes les lois," says M. Biot, "toutes les formules que nous venons de trouver ici pour les lames minces de chaux sulfatée s'étendent aussi aux lames minces de cristal de roche taillées parallèlement à l'axe, comme je m'en suis convaincu par l'experience; et non seulement la mode de polarisation est le même dans les deux substances, ainsi que l'ordre des teintes, et leur rapport avec les épaisseurs des lames, mais les valeurs absolues des epaisseurs sont aussi les mêmes, au moins dans les limites d'erreurs que comportent mes observations.

Je me suis egalement assuré que tous les autres cristaux doues de la double refraction offrent les mêmé lois de polarisation et les même périodes de couleurs quand ils sont réduits en lames minces parallèles à l'axe." Biot's *Traite de Physique*, tom. iv. p. 361. See also p 387.

[‡] After the table given by M Biot in his *Traite*, tom. iii. p. 350, including *Arragonite*, *Sulphate of Barytes*, *Topaz*, and *Sulphate of Lime*, he adds, "Tous les cristaux ci-dessus designés n'ont qu'un seul axe;" and afterwards, "Dans tous les autres, (all the rest, except *Mica*, in which the separation of the images cannot be studied,) la loi de Huygens a toujours paru s'appliquer exactement."

In the same year, viz. 1813, he discovered the same double system of rings in *Mica*, *Acetate of lead*, *Nitre*, *Mother-of pearl*, *Tartrate of potash and Soda*, and *Sulphate of potash*, and segments of coloured rings in various other bodies, such as *ice*, *amber*, and *hydrate of magnesia*.

In examining, during the same year, the *Oriental Ruby*, the *Emerald* and *Beryl*, Dr. Brewster discovered another system of rings, such as that shown in Fig. 8. where the rings are perfectly circular, and are intersected by a dark rectangular cross AB, CD; and in 1814, Dr. Wollaston discovered the same system of rings along the axis of *calcareous spar*.

During the continuance of his researches in the years 1815, 1816, and 1817, he found that by far the greater number of crystallized bodies possessed the double system of rings, one of which is shown in Fig. 7. and that in every case the phenomena of polarisation were distinctly related to the phenomena of double refraction; the one vanishing, and increasing, and decreasing, with the other.

ART. I. *On the System of Rings produced by Crystals with one Axis of Polarisation and Double Refraction.*

In examining the polarising structure of various bodies, Dr. Brewster found that the single system of rings represented in Fig. 8. was displayed along the axis of double refraction, as described in p. 704, 705, in the following bodies.

NEGATIVE CRYSTALS.

Carbonate of lime.
Carbonate of lime and magnesia.
Carbonate of lime and iron.
Tourmaline.
Rubellite.
Corundum.
Sapphire.
Ruby.
Emerald.
Beryl.
Phosphate of lime.
Idocrase.
Wernerite.
Mica from Kariat.
Phosphate of lead.
Phosphato-arseniate of lead.
Hydrate of strontites.
Arseniate of potash.
Muriate of lime.
Muriate of strontian.
Nitrate of soda.
Sub-phosphate of potash.
Sulphate of nickel and copper.

POSITIVE CRYSTALS.

Zircon.
Quartz.
Oxide of iron.
Tungstate of lime.
Titanite.
Boracite.
Apophyllite.
Sulphate of potash and iron.
Super-acetate of copper and lime.
Hydrate of magnesia.
Ice.

In examining the coloured rings produced by the different crystals in the table, we shall first consider the effect produced by plates of different thicknesses. If we take a rhomboid of calcareous spar, whose principal section is ABCD, Fig. 9. and cement upon its surfaces AB, CD, two prisms of flint glass, having their sides perpendicular to the principal section, and their refracting angles EBF, GDH, a little greater than FB *b*, which is 45° 23′ 26″; and if polarised light is incident perpendicularly upon the surfaces BE, DG, it will be transmitted parallel to B *b*,[†] and will exhibit, in the most beautiful manner, the system of coloured rings, shown in Fig. 8. Let the rhomboid ABCD be now cut into two plates, by any line MN, and let the rings, produced by each of the plates, be examined separately in the way already described: it will then be found that the squares of the diameters of the rings are in every case proportional to the numbers which represent the corresponding tints in Newton's table, (see p. 696,) and that the squares of the diameters of similar rings, as produced by plates of different thicknesses, are reciprocally proportional to the square roots of these thicknesses. These two results, which were first obtained by M. Biot, lead to the general conclusion, that the tints produced at different inclinations to the axis of the crystal, are to one another as the square of the sine of the angle which the polarised ray forms with that axis. Dr. Brewster found it perfectly correct in all the other crystals contained in the table; and it may therefore be considered as a general law, which we may apply with confidence in our future researches.

In order to apply it, however, with the utmost simplicity, our author has found it very convenient to consider every crystal as cut into a sphere, one of whose diameters is the axis of double refraction, and to suppose that the polarised ray passes through the centre of the sphere. By this means he has no occasion to consider the refractive power of the crystal, or the difference of thickness arising from oblique transmission; for the polarised ray is always incident perpendicularly, and the thickness of the sphere is every where the same. If in this sphere, AB, Fig. 10. is the axis of the system of rings, then P *p* may be called the *diameter of no polarisation*, or the *apparent axis of double refraction and polarisation*; P and *p* the *poles of no polarisation*; COD, *the equator of maximum polarisation*, and EF, and all the other parallels, the *isochromatic lines or curves of equal tint*. Now, since $\text{Sin.}^2\,\varphi$ represents the tint at any angle φ with the axis, we may, by determining experimentally the tint t, produced at any given thickness B, and at any inclination φ, find the maximum tint T, for that thickness, viz. $T = \frac{t}{\text{Sin.}^2\,\varphi}$, and the tint for any other thickness b will be $T = \frac{b}{B} \times \frac{t}{\mathrm{Sin.}^2\,\varphi}$. It is obvious, from these formulæ, that any given tint can be developed at any angle or distance from the axis, merely by varying the thickness of the crystal or the diameter of the sphere.

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[*] This is the inclination of ST, ST′ after refraction, or of Tv Tv′, their inclination before refraction being twice 60° 38′=121° 26′.

[†] This mode of exhibiting the coloured rings, is greatly superior to the mode employed by Biot, of grinding down the solid angles at B and D. Beside the advantage of procuring the greatest possible thickness from a given rhomboid, we preserve the polish of its natural faces, and the thickness of crystal through which the polarised ray passes can be calculated with the utmost accuracy from the thickness B *b* of the plate.

If it should be required to find the tints corresponding to any angle of incidence upon the natural faces of the crystal, we have only to consider the position of our sphere within the crystal, and compute the inclination of the refracted ray to the axis.

Although the systems of rings produced by all crystals with one axis, exhibit the same tints, and possess the same properties, yet those which are produced by the twenty-two crystals of the positive class, will be found to differ in one essential particular from the system produced by the negative crystals. If we take two rhomboids of calcareous spar, and place the one symmetrically on the other, the system of rings which they exhibit will be exactly the same as would have been produced by one rhomboid, whose thickness is equal to the sum of the thicknesses of the two which are combined. Dr. Brewster has been able to prove this by direct observation. He obtained a similar result by combining a plate of *beryl* with a plate of *calcareous spar;* for the system of rings will always be the same as would have been produced by two plates of beryl, one of which was the plate employed, and the other a plate which gave rings of the same size as the plate of calcareous spar.

But when we combine the system of rings produced by a crystal of *Zircon*, *Ice*, &c. with the system produced by *calcareous spar* or *beryl*, a very different effect is produced. The system of rings, instead of being diminished, is increased, and is equal to the system which would have been produced by a thin plate of calcareous spar, whose thickness is equal to the difference of the thicknesses of the plate of calcareous spar employed, and another plate of calcareous spar, that would give rings of the same size as those given by the zircon, &c. alone. This result, which our author succeeded, after much labour, in establishing experimentally, will also be obtained by substituting *Ice* in place of *Zircon. Quartz* cannot be employed in these experiments, as the system of rings is never complete, on account of the secondary tints seen along its axis. If the plate of *Zircon*, &c. gives a system of rings of the very same size as those of *Calcareous spar*, the one system will be completely obliterated by the other, and the combined crystals will exhibit neither double refraction nor polarisation. Hence it follows, that the twenty-two negative crystals form a class separate from all the other crystals in the table: This opposition in the action of crystals was first observed by M. Biot, in plates cut obliquely to the axis; and by this mode of observation he divided the crystals which he examined into two classes, in the following manner:

REPULSIVE CLASS.	ATTRACTIVE CLASS.
Calcareous spar	Rock crystal
Arragonite	*Sulphate of lime*
Beryl	*Sulphate of barytes*
Tourmaline	*Topaz.*

But since the crystals marked in italics have two axes of double refraction, and cannot be ranked in either class, the list, when corrected, will stand thus:

REPULSIVE CLASS.	ATTRACTIVE CLASS.
Calcareous spar	Rock crystal.
Beryl	
Tourmaline	

agreeing, in so far as it goes, with the more extended table which we have already given.

Hitherto we have considered the system of coloured rings as produced only near the axes of crystals, or as capable of being developed at any distance from the axis, merely by diminishing the size of the sphere; but there are two modes by which the rings can be rendered visible at any distance from the axis, and with any thickness of crystals.

If we take a prism of flint glass, with a large refracting angle, and examine through it the system of rings, we shall find that, instead of nine or ten rings, which are visible without the prism, we may reckon, by estimation, from 80 to 100 on that side of the axis towards which the refraction is made.

The other mode of developing the rings at any distance from the axis, and with any thickness of crystal, consists in crossing the tints with plates of *sulphate of lime.* If the axis MN, Fig. 8. of a plate of sulphate of lime, having such a thickness as to produce no coloured tints, even at a considerable obliquity, is placed in the direction of a diameter of the rings given by calcareous spar, a new system of rings will be produced at M and N, having their centres at O. The point where MN crosses the middle ring will be black, as the action of the calcareous spar is there exactly counterbalanced by the action of the sulphate of lime. The rings within the dark lines EF, GH, will be *positive*, in consequence of the action of the rock crystal predominating, and those without them will be *negative*, in consequence of the action of the calcareous spar predominating. If the plate of *sulphate of lime* produces the rings at *a*, *b*, instead of M, N, then, in the other two quadrants *c*, *d*, the tints will be those which are produced by the sum of the actions of the crystals, and the tints at *c* and *d* will be double of that which is produced at these points by the calcareous spar alone.

One of the most interesting features of the coloured rings, is the black cross AB, CD, where the two arms are exactly at right angles to each other. If the plate which produces this system of rings is turned round its axis O, the rings and the black cross will preserve an invariable position; CD being always in the plane of primitive polarisation, and AB in a plane perpendicular to it. Hence it follows, that whenever a plane passing through the axis of the crystal, is either in the plane of primitive polarisation, or perpendicular to it, the extraordinary pencil or tint disappears. This result will be found correct, whatever be the direction in which the polarised ray traverses the crystal, and is therefore the general law of the disappearance of the extraordinary pencil for crystals with one axis.

ART. II.—*On the Double System of Rings produced by Crystals with two Axes of Polarisation and Double Refraction.*

In the system of rings, seen along the axis of *Topaz*, as shown in Fig. 7. the inclination of the axes SV, S′V′, Fig. 6. was so great, that the mode in which the two systems of rings were connected, could not be at once rendered visible to the eye.

In *Nitre*, however, and other crystals, where the lines SV, S′V′, have a small inclination, the double system of rings, and the mode of their connection, may be exhibited with great facility. When a plate of nitre, about one-twelfth or one-fifteenth of an inch thick, and cut by planes perpendicular to the axis of the hexahedral prism, exposed at *e f* to polarised light ST, Fig. 4, and subsequently analyzed by the plate CD,—then at two rectangular azimuths of the plate *e f*, which we shall call 0°, and 90°, a double system of coloured rings will be seen, as at Fig. 11. where P, P′ are the centres of each system corresponding with the centres of the elliptical rings of topaz, as seen in Fig. 7. and AB, CD, a rectangular black cross.

The poles P, P′, of no polarisation, are distant 5° 20′, whatever be the thickness of the plate; and through them passes one of the branches CD of the rectangular cross AB, CD. The breadth of each ring is least between C and P, and D and P, and gradually increases towards AB, owing partly to the different thicknesses at which the light is transmitted through the plate.

When the plate of nitre is turned round its axis, the block cross ABCD immediately breaks up. The rings themselves have suffered no change by this change of position in the plate; but the black cross is separated into two hyperbolical branches M′P′N′, MPN, Fig. 12. When the thickness of the plate is above 3-10ths of an inch, the portions of the rings included between the two hyperbolic branches are confounded into one mass of white light, while those between C and P, or D and P, are distinctly visible. The concave sides of the hyperbolic branches are strongly fringed with a *red* and *yellow* colour, while the convex or inner sides are equally affected with *blue* rays. By diminishing the thickness of the plate, the rays gradually appear between the hyperbolic branches, but they consist only of *pink* and *green* tints, like those in the 5th order of Newton's scale; and even when the rings almost cease to appear by a great diminution of thicknesses, the tints, though at the very commencement of the first order, are not the same within as without the poles of no polarisation. In the position of Fig. 11, however, and when the tint at O, in the position of Fig. 12. is only *blue* of the first order, this irregularity of the tints is almost imperceptible, and the system of rings is distinguished from that produced by crystals with one axis only, by a slight degree of ellipticity. This approximation to the system, shown in Fig. 8. arises from the great attenuation of the crystallized plate, which is no longer capable of developing the tints between the poles of no polarisation; and it is only from the elliptical form of the curves that we can in this state recognise the existence of two axes. Even this ellipticity will disappear by a farther attenuation of the plate; and the crystal, deprived, as it were, of one of its axes, appears to act upon light exactly like beryl or calcareous spar.

The various minerals and crystals which possess this double system of rings, having already been given in page 707, and also the position of the line passing through O, or the principal axis of the crystal, it is unnecessary to repeat that list at present.

The most important physical circumstance which distinguishes the system of rings formed by different crystals, is the magnitude of the arch PP′, Fig. 11. which we have called the *inclination of the resultant axes*, or of the *diameters of no polarisation;* for it is from this angle alone that we can deduce the relative intensity of the real rectangular axes.

The following Table contains this angle for about 60 crystals. The measures were taken with great care, but some of them are only estimated, and others will admit of considerable correction by the use of better specimens than those which Dr. Brewster was able to procure.

	Names of Minerals.	Character of Principal Axis.	Inclination of Resultant Axes.
	Sulphate of nickel, certain specimens . .	+	3° 0′
	Carbonate of lead .	—	5 15
	Sulphato-carb. of lead .	—	
	Carbonate of strontites .	—	6 56
5	——— barytes .	—	
	Nitrate of potash .	—	5 20
	Mica, certain specimens	—	6 0
	Talc . . .	—	7 24
	Mother-of-pearl . .	—	11 28
10	Hydrate of barytes .	—	13 18
	Mica,* certain specimens, about	—	14 0
	Arragonite . .	—	18 18
	Prussiate of potash .	+	19 34
	Cymophane . .	+	27 51
15	Borax . . .	+	28 42
	Anhydrite† . .	+	28 7
	Apophyllite *biaxel* .	—	35 8
	Sulphate of magnesia .	—	37 24
	——— barytes .	+	37 42
20	Spermaceti, about .	+	37 40
	Tincal, or native borax .	—	38 48
	Nitrate of zinc, estimated at about		40 0
	Stilbite . . .	+	41 42
	Sulphate of nickel .	+	42 4
25	Carbonate of ammonia .	—	43 24
	Mica . . .	—	45 0
	Lepidolite . .	—	45 0
	Benzoate of ammonia .	+	45 8
	Sulphate of zinc .	—	44 28
30	——— magnesia and soda		46 49
	——— ammonia .	+	49 42
	Sugar . . .	—	50 0
	Sulphate of strontites .	+	50 0
	Murio-sulphate of magnesia and iron . . .	—	51 16
35	Sulphate of ammonia and magnesia . . .	+	51 22
	Phosphate of soda .	—	55 20
	Comptonite . .	+	56 6
	Sulphate of lime .	+	60 0
	Oxynitrate of silver .	+	62 16
40	Dichroite . .	—	62 50
	Feldspar . .	—	63 0
	Topaz, Aberdeenshire‡	+	65 0

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[*] Since these experiments were made, M. Biot found specimens of mica, in which the inclination was about 30°, 31°, 32°, 34°, 37°, and some under 25°.

[†] M. Biot has found the inclination of the axes of Anhydrite to be 44° 41′, so that the two substances must have been different. *Mem. Inst.* 1819

[‡] Brazilian topaz has been found by M. Biot and Dr. Brewster to have its inclination about 49° and 50. See *Mem. Inst.* 1819, and *Edin. Phil. Journ.* vol. v. p. 217.

	Names of Minerals.	Character of Principal Axis.	Inclination of Resultant Axes.
	Sulphate of potash	+	67 0
	Carbonate of soda	—	70 1
45	Acetate of lead	—	70 25
	Citric acid	+	70 29
	Tartrate of potash	—	71 20
	Tartaric acid	—	79 0
	Tartrate of potash and soda	+	80 0
50	Carbonate of potash		80 30
	Kyanite	+	81 48
	Hyper-oxymuriate of potash		82 0
	Muriate of copper		84 30
	Epidote, about		84 19
55	Peridot		87 56
	Crystallized Cheltenham salts		88 14
	Succinic acid, estimated at about		90 0
	Sulphate of iron, about		90 0

In examining the preceding Table, we cannot fail to be struck with the uniform distribution of the angles over the quadrant; a circumstance which contributes to render this new property of crystals a most distinct and valuable physical character in mineralogy.

In proceeding to explain the general law which Dr. Brewster discovered for determining the tints in crystals with any number of axes, let us suppose that ABC, Fig. 13 represents the quadrant of a spherical surface, such as we have described; and that the position of G, one of the resultant axes, where the tint is nothing, has been carefully determined by experiment, it is required to find the tint at E by the action of certain polarising forces which are in *equilibrio* at G. If we now suppose,

1*st*, That the tints are produced by forces emanating from *two negative axes*, whose poles are C, A, it is obvious that their relative intensities must be in the ratio of $1 : \frac{1}{\text{Sin.}^2\ GC}$, GC representing half the inclination of the diameters of no polarisation. For as the tint at G produced by A is equal to the tint produced at the same point by C, and since the tint produced there by the axis A is its maximum tint, AG being 90°, then the maximum tint produced by C will be found by the analogy $\text{Sin.}^2\ GC : \text{Rad.}^2 = 1 : \frac{1}{\text{Sin.}^2\ GC}$.

2*d*, If we suppose that the forces emanate from *two positive axes*, A, B, A being *greater* than B, then the relative intensities must be as $1 : \frac{1}{\text{Cos.}^2\ GC}$.

3*d*, If the forces emanate from two axes B, C, one of which is *positive* and the other *negative*, the intensity of B must be to that of C as $\text{Sin.}^2\ GC : \text{Cos.}^2\ GC$.

Through E draw three great circles AEF, BE and CE Fig. 13. and let

T = tint required at the point E.

θ = the arch between the point E and the axis C.

φ = the arch between the points E and B.

a = the tint produced separately at E by the greater axis.

b = the tint produced separately at E by the lesser axis.

ψ = the angle of the forces.

π = the angle BEF.

ω = the angle CEF.

A = the arch FC, or the angle CAF, or the *azimuth* on the great circle BGC, passing through the poles of no polarisation.

D = the arch FE, or the declination or distance of the point E from the same great circle.

ζ = half the difference of the angles at the base, or at the diagonal of the parallelogram of forces. Then

1. When the two axes are B, C, in the plane passing through the diameters of no polarisation, we have

$$\text{Cos. } \theta = \text{Cos. A} \times \text{Cos. D}.$$
$$\text{Cos. } \varphi = \text{Sin. A} \times \text{Cos. D}.$$

2. When the two axes are C, A, in a plane perpendicular to the plane passing through the diameters of no polarisation,

$$\text{Cos. } \theta = \text{Cos. A} \times \text{Cos. D}.$$
$$\varphi = 90^\circ - \text{D}.$$

Then we have, in general, whether the axes are A, C, or B, C.

$$\text{Cos. } \omega = \frac{\text{Tang. D}}{\text{Tang. } \theta}.$$
$$\text{Cos. } \pi = \frac{\text{Tang. D}}{\text{Tang. } \varphi}.$$

When B, C, are the two axes, either both *positive* or both *negative*,

$$\psi = 2\,\overline{\pi + \omega}.$$

When A, C, are the axes, either both *positive* or both *negative*,

$$\psi = 2\,(180^\circ - \omega) = 2\,\omega$$

When B, A, are the axes, either both *positive* or both *negative*,

$$\psi = 2\,(180 - \pi) = 2\,\pi.$$

When B, C, are the axes, the one *positive* and the *other negative*,

$$\psi = 180^\circ - 2\,\overline{\pi + \omega} = 2\,\overline{\pi + \omega}.$$

When A and C are both *positive*, or *negative*, and $C > A$,

$$a = \text{Sin.}^2\ \text{CE, and } b = \text{Sin.}^2\ \text{EA} + \text{Sin.}^2\ \text{GC}.$$

When A and B are both *positive*, or both *negative*, and $A > B$,

$$a = \text{Sin.}^2\ \text{AE, and } b = \text{Sin.}^2\ \text{BE} \times \text{Cos.}^2\ \text{GC}.$$

When B and C are the one *positive*, and the other *negative*,

$$a = \text{Sin.}^2\ \text{EC} \times \text{Cos.}^2\ \text{GC, and}$$
$$b = \text{Sin.}^2\ \text{BE} \times \text{Sin.}^2\ \text{GC}.$$

The tints produced separately by each axis being thus determined, *the tint resulting from their joint action will be found to be the diagonal of a parallelogram, whose sides are* a, b, *and whose angle is* ψ. In order to find this diagonal,

$$\text{We have Tang. } \zeta = \frac{a - b \text{ Tang. } \frac{1}{2}\psi}{a+b}, \text{ and}$$
$$\zeta + \tfrac{1}{2}\psi = \text{Greater angle at the base;}$$
$$\text{Hence} \quad T = \frac{a \text{ Sin. } \psi}{\text{Sin. } (\zeta + \frac{1}{2}\psi)}.$$

When $a = b$, then $T = 2\,a\,(\text{Cos. } \overline{\pi + \omega})$

When $a = b$, and the axes equal, then $\pi = \omega$, and

$T = 2a\,(\text{Cos. } 2\,\pi)$ or $T = 2\,a\,(\text{Cos. } 2\,\omega)$ and since $\varphi = \theta$

$$T = 2\ \text{Sin.}^2\ \varphi\ (\text{Cos. } 2\,\pi)$$

When $\psi = 90^\circ$ then $T = \sqrt{a^2 + b^2}$

When $\psi = 180^\circ$ $\qquad T = a - b$

When $\psi = 360^\circ$ $\qquad T = a + b$.

This general law of the tints may be expressed in the following manner: *the tint produced at any point of the sphere by the joint action of two axes, is equal to the diagonal of a parallelogram whose sides represent the tints produced by each axis separately, and whose angle is* *double of the angle formed by the two planes passing through that point of the sphere and the respective axes.*

If the crystal has three or more axes, the resulting tint produced by any two of them may, in like manner, be combined with the third, and this resulting tint with the fourth, till the general resultant of all the forces is obtained.

If the number of axes with given intensities exceeds *two*, they may be combined by the methods explained in the next section, till they are reduced to two axes, with new relative intensities; and the resultant of all the axes will be obtained by the calculation of the diagonal of a single parallelogram.

The law which we have now explained is obviously deduced from no empirical data, but is rigorously physical, and is founded upon the same principles which regulate the combination of all other mechanical forces. The accuracy with which it represents the complicated system of tints is very wonderful, and cannot fail to recommend it to the reception of philosophers as a true law of nature. In establishing its conformity with the actual phenomena, we shall submit it to the severe ordeal of M. Biot's measurements of the tints of *Sulphate of lime*, taken long before the discovery of the law, and which he considered as the result of irregular action depending upon imperfect crystallization. To those who may desire farther evidence, a still more decisive trial may be offered; a trial too, in which *the eye itself is capable of recognizing the perfect identity between the observed and calculated results.* If we compute all the tints, by means of the law, for any crystal in which the rings round the resultant axes can be seen at one view, and project them upon paper, after they are reduced to different thicknesses, corresponding to the oblique transit of the rays through the parallel plate, we shall have a representation of the rings actually observed, expressing in the most accurate manner all the inversions of the tints, and exhibiting the points of contrary flexure, and the innumerable varieties of form which the curves assume.

In order to determine the tints of sulphate of lime at great obliquities, M. Biot placed the laminæ in a tube shut up at both ends by plates of glass; and by means of a metallic rod he was able to fix them at any angle with the axis of the tube. He then filled the tube with *water*, or *oil of turpentine*, and observed the tints at inclinations as high as 78° 2′. In this way he constructed a formula which represented these observations, and by this formula he computed the following table, in which Dr. Brewcter has reduced his numbers, in order to represent the tints at equal thicknesses, by dividing them by the secants of the angles of refraction.

TABLE *of the tints of sulphate of lime in different azimuths reduced from* M. BIOT's *experiments.*

Angle of refraction.	Angular dist. from the axis.	Azimuth of 0°	Azimuth of 22° 30′	Azimuth of 45°	Azimuth of 67° 30′	Azimuth of 90°
0°	90°	1.0000	1.0000	1.0000	1.0000	1.0000
10	80	0.9768	0.9787	0.9838	0.9905	0.9944
20	70	0.9105	0.9164	0.9352	0.9615	0.9756
30	60	0.8101	0.8213	0.8600	0.9117	0.9434
40	50	0.6885	0.7047	0.7664	0.8523	0.9002
50	40	0.4559	0.5751	0.6607	0.7794	0.8482
60	30	0.4241	0.4409	0.5483	0.6982	0.7938
70	20	0.3027	0.3043	0.4121	0.5949	0.7337
80	10	0.2077	0.1599	0.2501	0.4060	0.6184
90	0					

In determining the tints by new experiments, Dr Brewster adopted two different methods of investigation. By one of these, which was analogous to that of M. Biot, he observed the tints for all angles of refraction up to 60°, and by another mode, he observed the remaining tints up to 90°, and he endeavoured to avoid as much as possible the secondary effects produced by obliquity.

The first of these methods is shown in Fig. 15. where ABCD is a plate of sulphate of lime, whose natural surfaces, AB, CD, are parallel to the plane passing through the resultant axes. Upon these surfaces he cemented two prisms of crown glass M, N, by a thin and equal film of Canada balsam, and having placed them upon the goniometer, he was able to observe the tints with great correctness at angles of refraction considerably beyond those which could be obtained in air. At angles of refraction between 60° and 90°, he resorted to the second method, which consisted in transmitting the polarised light through the parallel faces AD, AC. This method is attended with peculiar difficulties; and much perplexing labour must be submitted to before good plates can be obtained, as the laminæ are constantly separating from each other; and by admitting the materials employed in grinding and smoothing the surfaces, the transparency of the plate is destroyed. Dr. Brewster found it necessary, indeed, to bind the laminæ together by wax, sometimes by plates of wood, and at other times by placing them in a small hand vice. By these means his experiments at last succeeded, and all the mysterious actions of sulphate of lime, with the origin and classification of which M. Biot had been so much perplexed, were immediately unravelled. The two resultant axes and their attendant rings were observed at an angular distance of 60°; the relative intensities of the two axes, from which all the irregularities arose, were thus given, and the actual progress of the tints became a matter of simple observation. In this way Dr. Brewster constructed the following table.

Angle of refraction.	Angular dist. from the axis.	Azimuth of 0°	Azimuth of 22° 30′	Azimuth of the resultant axis 30°	Azimuth of 43°	Azimuth of 67° 30′	Azimuth of 90°
0°	90°	1.0000	1.0000	1.000	1.0000	1.0000	1.0000
10	80	0.978	0.979	0.980	0.984	0.992	0.995
20	70	0.913	0.919	0.927	0.938	0.962	0.973
30	60	0.811	0.824	0.835	0.861	0.913	0.939
40	50	0.689	0.710	0.729	0.768	0.853	0.898
50	40	0.558	0.576	0.588	0.662	0.782	0.850
60	30	0.435	0.438	0.448	0.538	0.719	0.810
70	20	0.340	0.294	0.304	0.410	0.659	0.775
80	10	0.274	0.125	0.154	0.305	0.614	0.760
90	0	0.250	0.105	0.000	0.246	0.597	0.753

In the preceding table, Dr. Brewster has not given the value of the tints to more than three decimal places, as even the third decimal place is partly the result of estimation.

In comparing these observations with the general law, we shall suppose that one of the axes has the same situation in the laminæ as the line which M. Biot calls the axis, when the other axis is perpendicular to the plane of the laminæ. These positions are indicated in Plate CCCCXXXVI. Fig. 13. by C and A. Since GC, therefore, or half the distance of the resultant axis, is 30°, we shall have the relative intensity of the axis C, to that of A, as $\frac{1}{\text{Sin.}^2 \text{GC}}$: or as 4 to 1. With these data the following table has been calculated.

Angle of refraction.	Angular dist. from the axis	Azimuth of 0°	Azimuth of 22° 30′	Azimuth of the resultant axis 50°	Azimuth of 45°	Azimuth of 67° 30′	Azimuth of 90°
0°	90°	1.0000	1.0000	1 0000	1.0000	1.0000	1.0000
10	80	0.9775	0.9796	0.9811	0.9848	0 9903	0.9925
20	70	0.9124	0.9202	0 9258	0.9401	0.9614	0.9707
30	60	0.8135	0 8272	0.8385	0 8660	0 9160	0.9375
40	50	0.6901	0.7093	0.7254	0 7729	0.8573	0.8967
50	40	0.5600	0.5755	0.5936	0.6593	0.7901	0.8533
60	30	0.4375	0.4356	0.4507	0.5339	0.7221	0.8125
70	20	0.3378	0.2980	0.3018	0.4071	0.6615	0.7792
80	10	0.2726	0.1238	0.1511	0.2983	0.6190	0.7575
90	0	0.2500	0.1035	0.0000	0.2500	0.6036	0.7500

The agreement between the numbers in this and the preceding table will convey an idea of the accuracy, with which the law accommodates itself to all the capricious changes of the tints. Dr. Brewster has compared it also with numerous experiments made on *nitre*, *mica*, *topaz*, *sulphate of iron*, &c. embracing all the varieties in the inclination of the resultant axes, and found it equally accurate in all these crystals. The projection of the calculated results, indeed, compared with the system of rings where their curvature is the most variable, may be considered as an *ocular demonstration of the correctness of the law.*

In examining the tints of crystals with two axes, and measuring the form of the fringes, Mr. Herschel found that they belonged to the class of curves called lemniscates, and that if ϕ, ϕ', represent the angles which any point forms with the two resultant axes P, P, the tints vary as $\text{Sin.}\,\phi \times \text{Sin.}\,\phi'$, so that if T is the maximum tint, the tint t at any other point of the paper is $t = \text{T}\ \text{Sin.}\,\phi \times \text{Sin.}\,\phi'$, a formula deducible from the general law discovered by Dr. Brewster.

Art. III. *On Crystals with three axes of Polarisation and Double Refraction.*

In the third section of Chap. VI. we have already explained the reasons why this class of crystals is supposed to have three axes of double refraction; but as the arguments there adduced are founded on the supposition, that *three equal axes of double refraction and polarisation, either positive or negative, destroy one another, or are in equilibrio in every point of the sphere*, we shall now give the demonstration, by which Dr. Brewster established the fundamental proposition on which the resolution and composition of polarising axes is founded.

Let A,B,C, Fig. 13. be the poles of the three axes, of which B,C are the positive axes, and A the negative axis.

The tint produced at any point E by the axis A alone, is of the same intensity, and the same character, as the tint that would be produced at the same point by the positive axes B, C, acting jointly Through E draw the great circles AEF, BE, and CE, and call $\text{EF} = x$, $\text{BE} = \phi$, $\text{EC} = \theta$, $\text{BF} = m$, $\text{CF} = n$, $\text{BEF} = \pi$, $\text{CEF} = \omega$. Then as the tint produced at E by the axes A alone is $\text{Sin}^2\ \text{AE}$ or $\text{Cos.}^2 x$, we must show that the resulting tint produced by the two axes B, C. is also equal to $\text{Cos.}^2 x$. By spherical trigonometry, we have

$$\text{Sin.}^2\,\varphi \times \text{Sin.}^2\,\pi = \text{Sin.}^2\,m$$

$$\text{Sin.}^2\,\theta \times \text{Sin.}^2\,\omega = \text{Sin.}^2\,\text{n}.$$

But since $m + n = 90^\circ$ $\text{Sin.}^2 n = \text{Cos.}^2 m$. Hence

$$\text{Sin.}^2\,m + \text{Sin.}^2\,n = 1,$$

and by adding together the two first equations, we have

$$\overline{\text{Sin.}^2\,\phi \times \text{Sin.}^2\,\pi} + \overline{\text{Sin.}^2\,\theta \times \text{Sin.}^2\,\omega} = 1.$$

Again, since $\text{Tang.}\,\varphi = \dfrac{\text{Sin.}\,\varphi}{\text{Cos.}\,\phi}$, and $\text{Tang.}\,x = \text{Tang.}\,\phi \times \text{Cos.}\,\pi$ and $\text{Cos.}\,\phi = x \times \text{Cos.}\,m$, we obtain by substitution

$$\text{Tang.}\,x = \frac{\text{Sin.}\,\phi \times \text{Cos.}\,\pi}{\text{Cos.}\,x \times \text{Cos.}\,m}\ \text{and}$$

$\text{Tang.}\,x \times \text{Cos.}\,x \times \text{Cos}\ m = \text{Sin.}\,\varphi \times \text{Cos.}\,\pi$; but since $\text{Tang.}\,x \times \text{Cos.}\,x = \text{Sin.}\,x$, we have $\text{Sin.}\,x \times \text{Cos.}\,m = \text{Sin.}\,\varphi \times \text{Cos.}\,\pi$, and by the same reasoning

$$\text{Sin.}\,x \times \text{Cos.}\,n = \text{Sin.}\,\theta \times \text{Cos.}\,\omega.$$

Hence, after squaring both equations, and adding them together, we have

$$\overline{\text{Sin.}^2\,x \times \text{Cos.}^2\,m} + \overline{\text{Sin.}^2\,x \times \text{Cos.}^2\,n} = \overline{\text{Sin.}^2\,\phi \times \text{Cos.}^2\,\pi} + \overline{\text{Sin.}^2\,\theta \times \text{Cos.}^2\,\omega}$$

$$\text{and } \text{Sin.}^2\,x = \frac{\overline{\text{Sin.}^2\,\phi \times \text{Cos.}^2\,\pi} + \overline{\text{Sin.}^2\,\theta \times \text{Cos.}^2\,\omega}}{\text{Cos.}^2\,m \times \text{Cos.}^2\,n}$$

But $\text{Cos.}^2\,m \times \text{Cos.}^2\,n = 1$. Hence,

$$\text{Sin.}^2\,x = \overline{\text{Sin.}^2\,\phi \times \text{Cos.}^2\,\pi} + \overline{\text{Sin.}^2\,\theta \times \text{Cos.}^2\,\omega}.$$

But since $\text{Cos}^2\,\pi = \text{Cos.}\,2\,\pi + \text{Sin.}^2\,\pi$ and $\text{Cos.}^2\,\omega = \text{Cos.}\,2\,\omega + \text{Sin.}^2\,\omega$, we have

$$\text{Sin.}^2\,x = \text{Sin.}^2\,\phi \times \text{Cos.}\,2\,\pi + \text{Sin.}^2\,\phi \times \text{Sin}^2\,\pi + \text{Sin.}^2\,\theta \times \text{Cos.}^2\,\omega + \text{Sin.}^2\,\theta \times \text{Sin.}^2\,\omega.$$

But $\text{Sin.}^2\,\phi \times \text{Sin.}^2\,\pi + \text{Sin.}^2\,\theta \times \text{Sin.}^2\,\omega = 1$; hence,

$$\text{Sin.}^2\,x = \text{Sin.}^2\,\phi \times \text{Cos.}\,2\,\pi + \text{Sin.}^2\,\theta \times \text{Cos.}\,2\,\omega + 1,$$

And since $\text{Cos}^2\,x = 1 - \text{Sin.}^2\,x$ we have

$$-\text{Cos.}^2\,x = \text{Sin.}^2\,\varphi \times \text{Cos.}\,2\,\pi + \text{Sin.}^2\,\theta \times \text{Cos.}\,2\,\omega.$$

Now, in the parallelogram of forces, the two forces AC, AD, Fig. 14. are $\text{Sin.}^2\,\phi$, $\text{Sin.}^2\,\theta$, when the axes are of equal intensity, that is $\text{AC} = \text{Sin.}^2\phi$, and $\text{AD} = \text{Sin.}^2\,\theta$. But

$\text{Sin.}^2\,\phi : \text{Sin.}^2\,\theta = \text{Sin.}^2\,\omega : \text{Sin.}^2\,\pi$, and the
Angle $\text{CAD} = 2\,\pi + 2\,\omega$. Hence,
$\text{CAB} = 2\,\pi$ and $\text{BAD} = 2\,\omega$. Consequently,
$\text{AF} = \text{Sin.}^2\,\phi \times \text{Cos}\ 2\,\pi$, and
$\text{BF} = \text{Sin.}^2\,\theta \times \text{Cos.}\,2\,\omega$, and therefore
$\text{AF} + \text{BF} = \text{AB} = \text{Sin.}^2\,\phi \times \text{Cos.}\,2\,\pi + \text{Sin.}^2\,\theta \times \text{Cos.}\,2\,\omega$,

which is the very same value which we have found above for $\text{Cos.}^2 x$, the measure of the tint produced by one axis.

Hence it follows, that the intensity of the tints, and consequently the form of the curves of equal tint, are the same, whether they are produced by one negative, or by two equal and rectangular positive axes.

We may therefore conclude,

1*st*, That a single negative axis may be resolved into two equal rectangular positive axes of the same intensity as the negative axis, and lying in a plane perpendicular to that axis.

This fundamental principle being established, we may proceed still farther in the resolution of the axes into axes of equal intensity, but differing in their character and position. Thus, in Fig. 13. the negative axis A being equivalent to the positive axes B,C, we may again resolve B into a negative axis at C, and another at A. Hence the original axis at A is equivalent to a negative axis at A, a positive axis at C, and a negative axis at C. But these two last axes destroy each other; and therefore the negative axis A is the only one that is left. If we also resolve the other positive axis C into two negative axes at A and B, we have the original negative axis A, equivalent to four negative axes, two at A, one at C, and one at B. We therefore conclude,

2*d*, That the effect of a single negative axis may be represented by three rectangular negative axes, provided two of them are equal, and the third has a greater intensity than the other two; and, *vice versa*, a single positive axis may be represented by three rectangular positive axes, provided two of them are equal, and the third has a less intensity than the other two.

Hence it follows, that by leaving one axis at A, the effect of the other three negative axes must be to destroy each other.

Or we may obtain the same result in the following manner: For since two equal positive axes are equivalent to one negative axis, of the same intensity as either of the two; and since this negative axis will be balanced by an equal positive axis coincident with it, it follows that the three rectangular positive axes will be in equilibrio. In perfect crystals of this class, where all the axes are equal, and their position exactly rectangular, the equilibrium of the forces is complete; but if the axes are not equal, or their position not accurately rectangular, the phenomena of one or more axes will be developed. If one axis, for example, is weaker than the other, then the result will be the appearance of an axis of an opposite name to that of the three axes, and coinciding with the resultant of the other two; but if one of the axes is stronger than the other two, the result will be an axis of the same name with the three axes, and coincident with the strongest axis

Our limits will not permit us to show the various methods of combining axes, particularly when they are not rectangular; but the reader will find this branch of the subject treated in detail in the *Phil. Trans.* 1818, p. 231. 245, &c.

SECT. V.—*On the deviation of the Polarised Tints from Newton's Scale.*

In all the investigations of M. Biot, the polarised tints are considered as exactly those of Newton's scale, (as given in p. 696.) with respect to the order and the proportions of the colours. This opinion, however, was completely overturned by the subsequent researches of Dr. Brewster, who showed that the system of coloured rings which he had discovered in apophyllite, had not the slightest resemblance to those of Newton's scale; that in all crystals with two axes, the tints in the neighbourhood of the resultant axes lost their resemblance to those of Newton's scale; that this deviation was greater in some crystals than in others, being a maximum in tartrate of potash, and soda, and acetate of lead; and that the crystals in which it existed might be divided into two classes, viz. those that have the *red ends of the rings inwards*, or towards the principal axis O, and those which have the *red ends outwards*, and the blue ends towards O. Thus,

Red Ends inwards.

Nitre.
Sulphate of barytes.
———— strontites.
Phosphate of soda.
Tartrate of potash and soda.
Super-tartrate of potash and soda.
Arragonite.
Carbonate of lead.
Sulphato-Carbonate of lead.

Red Ends Outwards.

Topaz.
Mica.
Anhydrite.
Native borax.
Sulphate of magnesia.

Deviation in the Tints, but the Position of the Red Ends undetermined.

Chromate of lead.[*]
Muriate of mercury.
Muriate of Copper.
Oxynitrate of silver.
Sugar.
Crystallized Cheltenham salts.
Nitrate of mercury.
Nitrate of zinc.
———— lime.
Superoxalate of potash.
Oxalic acid.
Sulphate of iron.
Carbonate of lead.
Cymophane.
Felspar.
Benzoic acid.
Chromic acid.
Nadelstein from Faroë.

In examining the rings formed by these bodies, Dr. Brewster discovered that the point of compensation, or the black spot in each system of rings from which the colours commenced, was not in the centre of the rings, and the position of this spot is given in his table of the colours of the rings in topaz.[†]

The subject of the deviation of the polarised tints from Newton's table, attracted the attention of Mr. Herschel, who conceived the idea of examining the coloured rings by homogeneous light. He proved not only that the magnitude of the rings varied in the different rays of the spectrum, but that the poles P, P', Figs. 11. and 12. of the resultant axes shifted their position, approaching to one another in red light, and receding in violet in some crystals, while in others they receded from one another in red, and approached to one another in violet. In sulphate of barytes, for example, Mr. Herschel found that the distances P, P' in *violet* light, was 66° 5′, and in *red* light 62° 2′, which gives the apparent separation of the axes 2° 1′ 30″. In Rochelle salts, or tartrate of potash and soda, the real inclination of the axes in *red* light was 75° 42′, and in *violet* light only 55.° 14′.

This discovery of Mr. Herschel cannot fail to be considered as one of the highest importance, not only as furnishing a complete explanation of the irregularity of the tints in crystals with two axes, but as affording a decisive proof that the resultant axes of crystals are not the real axes from which the forces emanate, the phenomena being related to two rectangular axes, coincident with prominent lines in the primitive forms of the crystal; for if this were not the case, tartrate of potash and soda would have an infinity of axes of double refraction dispersed over two arches of 5° each. Mr. Herschel has himself maintained this conclusion with great force of argument, and has established beyond a doubt the truth of Dr. Brewster's theory of rectangular axes.

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[*] There is a *bright blue* light at one end of the system of rings, and a *bright red* light at the other end.

[†] *Phil. Trans.* 1814, p. 204, 205.

The anomalous tints of apophyllite furnish us with a still more extraordinary deviation from the colours of Newton's scale, and as this crystal has only one apparent axis of double refraction, the difficulty of explaining them is greatly increased.* In the paper in which Dr. Brewster first gave an account of these tints, he considered them as proving that this crystal had negative axes lying in the plane of the laminæ. Mr. Herschel examined the phenomena of apophyllite with peculiar attention. By exposing it to homogeneous light, he found that some specimens gave rings of nearly the same size in all the different colours of the spectrum; and, what is extremely remarkable, that some specimens exercise a *negative* action upon one end of the spectrum, a *positive* action upon the other end, and *no action at all* upon the mean rays.

This very singular fact, of which Mr. Herschel does not give any explanation, has been recently studied by Dr. Brewster. In order to ascertain how far it might be general, he examined various apophyllites of Faro, Uto, Faroë, and Iceland, and he invariably found, by effecting a separation of the images, that the doubly refracting force was positive or attractive, like that of *quartz*, whether the ray was *red*, *blue*, or *yellow*. He therefore regarded it as an accidental anomaly, having its origin in some peculiar relation of the polarising doubly refracting forces of particular specimens of apophyllite.

As there are specimens of apophyllite with two axes, as well as with one, and as the intensity of one of these axes varies in different parts of the same crystal, as will afterwards be described, Dr. Brewster explains all the phenomena upon the supposition that it has three rectangular axes, nearly, but not accurately in equilibrio.

In the *Biaxal* apophyllite, says he, one of the polarising axes *must* be in the plane of the laminæ, and in both the *Biaxal*, and *Uniaxal* apophyllite, there appears to be an axis perpendicular to the laminæ. As the form of the prism of apophyllite is perfectly symmetrical in relation to the axis, it is probable that there are two equal and rectangular axes, of a *positive* or *attractive* character, in the plane of the laminæ, each axis being perpendicular to the parallel faces of the crystal; and we know that there is a *positive* or *attractive* axis at right angles to the laminæ, and coincident with the axis of the prism. The two equal *positive* axes, which we shall call the *horizontal* axes, on the supposition that the prism is placed on its base, will obviously produce a single *negative* axis, coincident with the other *positive* axis, or the *vertical* one perpendicular to the laminæ, and the system of rings round the resultant of these two axes will deviate more or less from Newton's scale, according to the nature of the dispersive forces of the elementary axes. Let us suppose that the resultant negative vertical axis has the same action upon the *yellow* rays of the spectrum, as the real positive vertical axis; but that it acts much more energetically upon the *red* extremity, and much less energetically upon the *blue* extremity, of the spectrum. The *yellow* rays being thus solicited by equal and opposite forces, the crystal will exercise over them no polarising energy. The *red* rays being subjected to a greater polarising energy from the *negative* than from the *positive* axis, will give rings corresponding to the difference of their opposite actions, and the characters of these rings will be *negative*. The *blue* rays, on the contrary, being much less energetically acted upon by the *negative* than by the *positive* axis, will form rings proportional to the difference of their actions, and these rings will be *positive*, from the predominating influence of the positive axis.† In this way a particular crystal of apophyllite may exercise over the red rays of the polarised beam a negative influence; over the blue rays a positive influence; and over the yellow rays no influence at all; while it is the general character of the mineral to exert an attractive doubly refracting force over all the rays of the spectrum. The ray of compensation, in place of being yellow, may have any position in the spectrum, and those on each side of it will afford positive or negative tints, according as the positive or the negative axis exercises over them a predominating influence. This explanation may be presented in a more brief form, by stating that the specimen of apophyllite in question had three positive rectangular axes, which were in equilibrio only for the yellow rays of the spectrum; and in this point of view the phenomena belong to the case of three imperfectly balanced axes, which is described in the *Phil. Trans.* 1818, p. 256.

This view of the polarising structure of apophyllite affords a complete explanation of the singular tints which surround its resultant axis. Each order of colour is, as it were, a residual spectrum, arising from the opposite actions of the negative and the positive axis, and the tints of which these orders are composed will consquently vary, according to the locality of the ray of compensation.

For farther information upon the subject of this section, see Dr. Brewster's papers, *Phil. Trans.* 1814, p. 204, 205; *Phil. Trans*, 1818, p. 242, 243, 256, 257; *Wernerian Memoirs*, vol. iii. p. 68; *Edin. Phil. Journal*, vol. i. p. 5; and *Edin. Transactions*, vol. ix, part ii. p. 329—333; and Mr. Herschel's papers, in the *Phil. Trans.* 1820, p. 76, &c.; *Memoirs of the Cambridge Philosophical Society*, vol. i. part i. p. 21; and part ii. p. 241; or in the *Edin. Phil. Journal*, vol. iv. p. 334; vol. v. p. 334; and vol. vii. p. 136 and 143.

SECT. VI. *On Circular Polarisation in Rock Crystal and certain Fluids.*

In examining the polarised tints of Quartz, M. Arago observed along the axis certain colours, which appeared to differ in their nature from the ordinary tints of the mineral, though they increased and diminished by varying the thickness of the plate. The phenomena were subsequently analyzed by M. Biot, who observed, that in certain specimens of quartz the colour along the axis descended in the scale, by turning the analyzing prism from *right* to *left*, while in others the same tint descended in the scale by turning the prism from *left* to *right*. From these facts, M. Biot conceived the hypothesis, that the first kind of quartz impressed upon the particles of polarised light a rotatory motion from right to left, while the other kind gave it a rotatory motion from left to right; that this property belonged to the ultimate particles of silex, and that it was quite independent of the crystallization of the quartz, or the mode of aggregation of its particles.

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* Mr. Herschel discovered anomalous tints in the *hyposulphate of lime*, a crystal with one negative axis. *Mem. of Cambridge Phil. Soc.* vol. i.

† We have no doubt but that Apophyllites will be found in which the axis is *negative* for all the rays of the spectrum.

In analyzing the phenomena themselves, M. Biot found that they could be explained, by supposing the axes of polarisation of the luminous rays to have a progressive rotation; and that the rapidity of this rotation increased with the refrangibility of the rays; the violet rays turning more rapidly than the blue, and the red ones revolving slower than the rest. By employing plates of rock crystal of various thickness, he found that the arcs of rotation were proportional to the thickness of the plates, and that in the same plate they were reciprocally proportioned to the squares of the lengths of their fits, or to the squares of the lengths of the vibrations in the system of undulations. The following Table contains the arcs of rotation of differently coloured rays, as produced by a thickness of one millimetre of rock crystal, to which we have added the results of M. Fresnel's formula, already noticed.

	Arc of Rotation observed.	Arc of Rotation calculated from M. Fresnel's Experiments.
Extreme red - - - -	17.4964	
Mean red - - - - -	18.9881	18.9881
Limit of red and orange -	20.4798	
Mean orange - - - -	21.3968	21.5105
Limit of orange and yellow	22.3138	
Mean yellow - - -	23.9945	23.9628
Limit of yellow and green	25.6752	
Mean green - - - -	27.8606	27.3960
Limit of green and blue -	30.0460	
Mean blue - - - -	32.3088	31.1097
Limit of blue and indigo -	34.5717	
Mean indigo - - - -	36.1273	34.1225
Limit of indigo and violet	37.6829	
Mean violet - - - -	40.8828	37.4860
Extreme violet - - -	44.0827	

The connexion between the phenomena of circular polarisation and those of the common polarised tints has been discovered by M. Fresnel. Having taken two oblique angled parallelopipeds, like ABCD, Fig. 16. he allowed a polarised ray RS to suffer two total reflexions with the parallelopiped at S and S′, and having received the emergent ray S′T upon a thin plate of sulphate of lime, having its axis inclined 45° to the plane of reflexion TS′S, the transmitted ray was again allowed to suffer two total reflexions within another parallelopiped, having its plane of reflexion inclined 90° to the plane of the first, and of course 45° to the axis of the sulphate of lime. Upon examining the light thus modified, he found that it had all the properties of light transmitted through a certain thickness of rock crystal perpendicular to the axis. See the History of Optics, p. 624, col. 2.

In repeating the experiments which had been made in circular polarisation, Dr. Brewster observed that the tints seen along the axis of rock crystal obliterated the arms of the black cross, as shown in Fig. 17. which characterizes every single system of coloured rings. By making the plate of *quartz* extremely thin, he caused the arms of the black cross to re-appear, and they became still more distinct by turning the prism into the position that gave the minimum or faint circular tint that still remained. By combining also two plates of quartz of the same thickness, but which turned the planes of polarisation in opposite directions, he obtained a resultant system of rings free of any of the circular tints, and having the black cross in the most perfect manner.* Hence it followed, that all the ordinary tints, viz. those of the first order, and produced along the axis of other crystals, were produced in the most perfect manner by quartz, and were merely obliterated by the circular tints.

In examining the structure of the amethyst, Dr. Brewster found that this mineral possessed the singular property of uniting the two kinds of quartz that turned the planes of polarisation both from *left* to *right*, and from *right* to *left*. These two kinds of quartz are arranged in veins as represented in Figs. 18 and 19. In Fig. 18. the shaded veins which correspond to each alternate face of the pyramid turns the planes of polarisation from *right* to *left*, while all the rest of the crystal turns the same planes from *left* to *right*; and, what is very interesting, the black lines where these two structures unite have no action whatever on the planes of polarisation. In some specimens these opposite veins are so very minute that they destroy each other's action upon the polarised ray, and when this happens, the single system of rings appears with its black cross, and entirely free of any of the tints of circular polarisation. The colouring matter of the amethyst is arranged in a very singular manner in relation to these veins; and the fracture across the veins exhibits a beautiful, and sometimes a regular rippled structure, resembling the engine turning a watch, and affords an infallible mineralogical character of the amethyst, whether its colour is *yellow*, *orange*, *olive*, *green*, *blue*, or perfectly colourless.

The general structure of well crystallized amethysts is shown in Fig. 19. which is of the natural size, and is taken from one of the finest specimens that Dr. Brewster met with. "On the three alternate sides of the prism," says he, viz. "MN, OP, and QR, are placed sectors M *e* N, O *d* P, Q *a* R, which are divided into two parts by dark lines *c c′* : *d d′*, *a d′*, which separate the direct structures of A, C, and E, from the retrograde structures of B, D, and F. On the other three alternate faces of the prisms are placed the three veined sectors M *c b a* R, N *c b d* O, and P *d b a* Q, which meet at *b* in angles of 120°, and consist of veins of opposite structure, alternating with each other, and so minute, that in many places the circular tints are almost wholly extinguished by their mutual action. The direct sectors A, C, and E, are all connected together by the three radial veins *b a*, *b c*, *b d*, and are therefore to be considered as the expanded terminations of these veins. The retrograde sectors B, D, and F, are expansions of the first retrograde veins next to *b d c*, *d b a*, and *a b c*; and the lines *c c′ d d′*, and *a a′*, are continuations of the dark or neutral lines which separate the first retrograde vein from the direct radial veins.

All the sectors A, B, C, D, E and F, are of a *yellowish brown* colour, and all the rest of the crystal is of a *pale lilac* colour, the lilac tints being arranged in the manner previously described. The phenomena which I have now mentioned as existing in this specimen are very common in the amethyst; and I have never yet found a specimen, in which the yellow tints were not confined to those portions which formed the expanded terminations of veins; a fact which indicates that this would have been the colour of the crystal, whether its action were direct or retrograde, and that the lilac colour affects in general those portions which are composed of opposite veins."

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* M. Biot had long before found, that the two opposite circular tints destroyed one another, but without any reference to the system of rings.

In order to determine whether or not the phenomena of circular polarisation, as M. Biot maintained, arise from the ultimate particles of silex, Dr. Brewster examined *opal* and *tabasheer*, but could not detect the slightest trace of such a property. He then conceived the idea of examining *quartz that had been melted by heat*, and having received from Dr. Hope a piece which that eminent chemist had reduced to fusion, he found that it did not exhibit the slightest trace either of common or circular polarisation.

A very important discovery relative to circular polarisation, was some time ago made by Mr. Herschel. Impressed with the idea that this property might be related to some crystalline structure in quartz, he examined different specimens of that variety, which is called by Hauy *Plagiedre*, and which possess unsymmetrical faces x, x, x, x', x', x', Fig. 20. that always lean in one uniform direction round the summit A, but sometimes to the *right* and sometimes to the *left*; he submitted these crystals to examination; and though M. Biot, as Mr. Herschel remarks, assures us that no peculiarity in the crystalline form can lead us to conjecture the direction of rotation; yet he found in every case, after examining *fifty-three* different crystals, that the direction in which they turned the planes of polarisation was invariably the same as the direction in which the plagiedral faces leant round the crystal. Hence Mr. Herschel concludes that *these faces are produced by the same cause which determines the displacement of the plane of polarisation of a ray traversing the crystal parallel to its axis.*

In examining so many crystals of quartz, Mr. Herschel remarked, that the number of those in which the plagiedral planes have an inclination to the left, is to the number of those which have them in the opposite direction as *two* to *one* nearly. Mr. Herschel likewise found by preparing the *liquor silicum* (a solution of silica in potash) from a portion of a plagiedral crystal that turned the plane of polarisation to the left, that it exhibited none of the phenomena of circular polarisation. See the works quoted at the end of the next section.

SECT. VII.—*On Circular Polarisation in Fluids.*

MM. Biot and Seebeck discovered about the same time that certain fluids exhibited the phenomena of circular polarisation, but in a very weak degree; but it is to the former that we owe the analysis of this class of phenomena. Having filled a tube six or seven inches long, and containing oil of turpentine, and placed it in the apparatus shown in Fig. 4, he observed the complimentary colours, which had the same property as those produced by a plate of rock crystal, which turned the planes of polarisation from right to left. By trying other fluids, he obtained the following results.

From Right to Left.	*From Left to Right.*
Oil of turpentine.	Essential oil of lemons.
Essential oil of laurel.	Solution of natural camphor in alcohol.
Solution of artificial camphor in alcohol.	Syrup of sugar.
Vapour of turpentine.	

M. Biot found that the tints rose in the scale as the thickness of the fluid was increased;—that oil of turpentine, mixed with another fluid that has not the power of acting upon light, gave a tint proportional to the number of particles of turpentine in the mixture; and that, when two fluids that turned the planes of polarisation in opposite directions, were mixed in quantities reciprocally proportional to the intensity of the action, they neutralised one another. He found also that oil of turpentine required to have a thickness of $68\frac{1}{2}$ millimetres to give the same tint as a single millimetre of quartz; that a thickness of 38 millimetres of oil of lemons was equal to a thickness of 66 of oil of turpentine; and that a thickness of $4\frac{1}{2}$ millimetres of concentrated syrup of sugar was equal to one millimetre of quartz.

The action of these different fluids on the differently coloured rays, followed the same laws as in rock crystal.

By using two columns of essence of turpentine, 0.50 and 2.030 millimetres thick, M. Fresnel deduced the following arcs of rotation for the different rays for a centimetre of thickness.

Mean Red	-	2.59	2.71
Orange	-	2.99	3.07
Yellow	-	3.36	3.42
Green	-	3.90	3.91
Blue	-	4.48	4.44
Indigo	-	4.96	4.87
Violet	-	5.49	4.35

By comparing the results in the 2d column, which M. Fresnel conceives to be the most correct, with the arc produced by a continuation of rock crystal in the mean red ray, M. Biot finds the relative intensities of oil of turpentine and quartz to be as 1 to 70.0678, and from this data he computed the 2d column in the table in p. 732.

For farther information on the subject of this and the preceding section, see M. Biot's *Traité de Physique*, tom. iv. p. 539; *Mem. de l'Institut*, 1818; *Edinburgh Transactions*, vol. ix. p. 139; *Memoirs of the Cambridge Society*, vol. i. No. 1; and the *Edin. Phil. Journal*, vol. iv. p. 371. 433, and vol. vi. p. 379.

SECT. VIII.—*On Singly Polarising Crystals.*

ART. 1. *On Natural Singly Polarising Crystals.*

During his earlier experiments on the polarisation of light, Dr. Brewster discovered, in 1812, the singular property possessed by the agate, of polarising *in one plane* all the light which it transmits in the formation of a distinct image of any luminous object; and in consequence of its possessing this property, he used plates of agate, and also agate microscopes, for polarising light, and for analyzing the pencils transmitted through regular crystals. Upon examining the phenomena of this mineral with more minute attention, he found that the bright image was actually enveloped in a mass of nebu-

'ous light, polarised in an opposite plane to the light of the distinct image. In some agates, imperfectly formed, two images were produced; and in other specimens of an intermediate character, the one image was much fainter than the other;[*] and therefore a part of its light must have been lost either by reflexion or absorption, or from both causes. In some specimens, the light of the bright image gradually assumed a *red colour*, and vanished when the obliquity was considerable. In some specimens of the agate there was an approach to the system of rings in quartz; and in all of them, when reduced to a sufficient degree of thinness, the tints of moveable polarisation were developed in an irregular manner, the axis of one part of the crystal being inclined to the axis of the other parts.[†]

The phenomena of single refraction were also observed by Dr. Brewster in the massive *carbonate of barytes.* In some directions, two images were seen of *different intensities*, and in others only one, accompanied with a nebulous mass oppositely polarised. In some directions, the least refracted image was extremely distinct, while the other was a faint nebulous image, of a *brownish-red* hue.[‡]

In plates of *Mica*, 0.127 and 0.093 of an inch thick, the same author produced the phenomena of single refraction by inclining the plate; and in a every position of these plates beyond a certain angle of inclination, the transmitted light was all polarised in one plane, and in an opposite manner to the light polarised by the reflexion, and, consequently, the light of the other image must have been lost either by reflexion or absorption, or by both.

Of all these cases of single refraction, the most remarkable is that which is produced by the absorption of direct and polarised light in *mother-of-pearl.* When a ray falls at an angle of about 60°, on a plate of this substance, about the 40th of an inch thick, the *transmitted ray is polarised in the same manner as the reflected ray;* and the same effect is produced by turning round the plate, provided the inclination of the ray remains the same.[§] Hence, as mother-of-pearl is a negative doubly refracting crystal, like mica, it follows, that while the *ordinary* ray is absorbed or lost in the one crystal, the *extraordinary* ray is absorbed or lost in the other. This very singular effect would admit of explanation, if we could suppose laminæ perpendicular to the surface of the plate, and so arranged as to have their planes of reflexion perpendicular to the plane of incidence of the primitive ray. But as this seems out of the question, we can only refer the fact to a specific action of mother-of-pearl in absorbing light polarised in a particular plane.

Among the phenomena of nebulous images accompanying double refraction, there is none more extraordinary than those which appear in the form of luminous sectors in *Oil of Mace* melted, and gradually cooled between two plates of glass. When we look at the direct light of a candle through particular parts of this plate, the candle appears surrounded with a halo or nebulous mass, varying from 0° to 16° in diameter, and having its central parts of a bluish colour, and its circumference of a reddish brown hue. When the polarised light of a candle is transmitted through those parts that produce the halo, the plate depolarises four *luminous sectors*, as shown in Fig. 21. where AB is the plane of polarisation, M, N, the two images formed by an analyzing prism of calcareous spar, *m* the place of the vanished image, and *n* the visible image. The evanescent image *m* is surrounded with four luminous sectors, 1, 3, 5, 7, separated by four dark ones, 2, 4, 6, 8, and the bright image *n* is also surrounded with four sectors, 9, 11, 13, 15, separated by dark sectors, 10, 12, 14, 16; but these sectors, of which 11 and 15 are the brightest, are less luminous than those round *m*.

As the luminous sectors do not appear without using the analysing prism, it is obvious that the nebulous image consists of two superimposed images, as in Fig. 22. each sector in the one being oppositely polarised to the corresponding sector of the other. The polarisation of the light in the sectors, and all the phenomena of oil of mace, are capable of being explained by supposing the crystals grouped round a centre, and having their axes all directed to that centre. When the axes of these crystals are either parallel or perpendicular to the plane of polarisation, the light which they polarise will vanish as at 2, 4, 6, 8, and when the axes are inclined 45° to the same plane, the light will appear as at 1, 3, 5, 7.[‖]

A very curious example of single refraction or absorption was observed by Dr. Brewster in a prism of *Nitrate of Potash*, through which he observed its system of coloured rings by simple exposure to direct light, and without either polarising the incident pencil or analysing the transmitted rays.

In the *Annales de Chimie* for May, 1815, M. Biot published an account of the property of single refraction, which he had found in the tourmaline, and which had been discovered about the same time by Dr. Seebeck. When plates of tourmaline are cut by planes passing through the axis of the crystal, they transmit only the rays of the extraordinary pencil, polarised in a plane perpendicular to the axis of the prism, provided the plates are above a certain degree of thickness. Below this degree of thickness, which is variable in different tourmalines, the crystal has double refraction like all others, and consequently at different thicknesses below that which extinguishes the ordinary ray; this ray will gradually become more and more intense, constantly approximating to the intensity of the extraordinary ray. M. Biot observed the two images when seen in this way, and noticed that the ordinary one was of a greenish yellow colour, while the extraordinary one was whitish, the very same fact which Dr. Brewster had long before found in carbonate of barytes, and he concluded that the violet rays were more easily absorbed by the tourmaline when they were polarised parallel to its axis, than when they were polarised perpendicularly to it.

Independent of the crystals enumerated above, there are many organized substances, in which one of the polarised images has less intensity than the other, and in which, therefore, a portion of one of the pencils has been lost or absorbed.[¶]

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[*] *Phil. Trans.* 1813. p. 103, 104.

[†] *Edin. Trans.* vol. vii. p. 289, read Feb. 7, 1814.

[‡] *Phil. Trans.* 1814, p. 194.

[§] *Phil. Trans.* 1814.

[‖] See *Phil. Trans.* 1815, p. 38. 49. read December 15, 1814, where several other curious phenomena, exhibited by oil of mace, are described.

[¶] See *Phil. Trans.* 1815, p. 27.

Art. II.—*On Artificial Singly Polarising and Refracting Crystals.*

In all the singly refracting and polarising crystals above enumerated, the effects described arise from a certain degree of imperfection in the structure and combination of the elementary crystals, by which one of the polarised pencils is reflected or absorbed; but Dr. Brewster found the same property may be communicated to any crystal merely by altering its superficial conformation.

If we take a hexahedral prism of *nitrate of potash*, and observe a luminous object through two of its inclined surfaces that have a good natural or artificial polish, we shall perceive two distinct and perfectly formed images. If we now roughen these two surfaces, and cement upon each of them a plate of glass by means of *balsam of capivi*, the character of the two images will be greatly changed. The image that has suffered the greatest refraction, will be as distinct as before, but the other image will be either of a faint reddish colour, or wholly invisible, according to the degree of roughness induced upon the refracting surfaces. When *oil of cassia* is used instead of the balsam, the least refracted image, if it was visible before, will now be completely extinguished.

By substituting pure *alcohol*, or the *white of an egg*, instead of the balsam, the least refracted image will become distinct, and the most refracted image will be either a mass of nebulous light, or almost invisible.

In order to explain these phenomena, we must recollect that the index of refraction for the *ordinary* image of nitre is 1.511, and that of the *extraordinary* image 1.328. When the rough surface of the nitre is covered with balsam of capivi, which has nearly the same index of refraction as the ordinary image, the same effect is produced as if the rough surface had been polished for the ordinary rays. All the little pits, or depressions in the rough surface, being filled up with balsam, the ordinary rays suffer little or no refraction in penetrating the crystal, and therefore the image which they form will be as clear and distinct as in the first experiment. But since the index of refraction for the extraordinary image is much less than that of the balsam, the rays of which it is composed will not enter the crystal undisturbed, but will be scattered in the same manner as if its surface was rough, and had a refractive power corresponding to the difference between the index of refraction for the extraordinary ray, and the index of refraction for the balsam. When *water* or *alcohol* is substituted in room of the *balsam*, the effects now described are interchanged, the roughness being removed for the extraordinary rays by the application of a fluid of the same refractive density, while the rays that form the ordinary image are dispersed by the refractions which still exist at the rough surface of the crystal.

These effects will be still better understood by supposing the crystal to consist of an extraordinary and an ordinary medium, arranged in alternate strata, or as water exists in wet hydrophanous opal. When the superficial polish of both these media is removed, the application of the *balsam* restores, as it were, the polish of the ordinary medium, without restoring that of the extraordinary medium; while the application of the *alcohol* restores the polish of the extraordinary medium without restoring that of the ordinary medium.

These results were repeatedly obtained with *calcareous spar*, *arragonite*, *nitre*, *carbonate of potash*, and other crystals. See *Phil. Trans.* 1819, p. 146.

Sect. IX.—*On the Absorption of Common and Polarised Light.*

When light is said to be *absorbed* by any transparent or translucent medium, all that is meant is, that a certain quantity is lost in passing through that medium, either from being dispersed in all directions by reflexion from its particles, or by being assimilated to the substance of the body, or by both of these causes together.

Art. I.—*On Dichroism, or the Absorption of Common Light by Crystallized Bodies.*

The term *Dichroism*, from *δυο two*, and *χροα colour*, is applied to denote the two colours, which Dr. Wollaston long ago observed in *Tourmaline*, and certain crystals of *Palladium*, and which Cordier afterwards observed in the *Iolite* or *Dichroite*. The cause of this phenomenon was entirely unknown till Dr. Brewster investigated its origin in the Iolite, and showed that the two colours were related to its two resultant axes of double refraction, and arose from the absorption of the transmitted rays, when exposed only to common light, and according to laws depending on the position of the incident ray in reference to its axes of double refraction.

The curious mineral called *Iolite*, from its bluish violet colour, crystallizes in six or twelve-sided prisms, which appear of a *deep blue colour*, when seen along the axis, and of a *yellowish-brown colour*, when seen in a direction perpendicular to the axis. If *a b c d*, Fig. 23. is a section of a prism of Iolite, by a plane passing through the axis of the prism, the transmitted light will be *blue* through the faces *a b*, and *d c*, and *yellowish-brown* through *a d*, *b c*, and in every direction perpendicular to the axis of the prism. If we grind down the angles *a*, *c*, *b*, *d*, so as to replace them with faces *m n*, *m' n'*, and *o p*, *o' p'*, inclined 31° 41′ to *a d*, or to the axis of the prism; then, if the plane *a b c d* passes through the resultant axes of double refraction, we shall observe, by transmitting polarised light through the crystal in the directions *a c*, *b d*, and subsequently analysing it, a system of rings round each of these axes. The system will exhibit the individual rings very plainly if the crystal is thin; but if it is thick, we shall observe, when the plane *a b c d* is perpendicular to the plane of primitive polarisation, *some branches of blue and white light, diverging in the form of a cross from the centre of the system of rings*, or the poles of no polarisation, as shown at *p* and *p'*, Fig. 24. where the shaded branches represent the blue ones. The summits of the blue masses at *p* and *p'* are tipped with purple, and are separated by whitish light in some specimens, and yellowish light in others. The white light becomes more blue from *p* and *p'* to *o*, where it is quite *blue*, and more yellow from *p* and *p* to *c* and *d*, where it is completely *yellow*. When the plane *a b c d* is in the plane of primitive polarisation, the poles *p*, *p'* are marked by spots of white light, but every where else the light is a deep blue.

In the plane *c a d b*, Fig. 23. the mineral, when we look through it at common light, exhibits no other colour but yellow, mixed with a small quantity of blue, polarised in an opposite plane. The ordinary image at

c and d is yellowish-brown, and the extraordinary image faint blue; the former acquiring some blue rays, and the latter some yellow ones from c and d to a and b, where the difference of colour is still highly marked. From a and b towards p and p', the yellow image becomes fainter, till it changes into blue, and the weak blue image is reinforced by other blue rays, till the intensity of the two blue images is nearly equal. The faint blue image increases in intensity as the incident ray approaches from c and d to p and p', and the yellow one, acquiring an accession of blue light, becomes bluish white. From p and p' to o, the ordinary image is whitish, and the other deep blue, but the whiteness gradually diminishes towards o, where they are both almost equally blue.

The principal axis of Iolite is negative, and its greatest refracted image is purplish blue, while the ordinary or least refracted image is yellowish brown, passing into one another as above described.

In *Augite*, one of the pencils is of a *deep blood red colour*, while the other is of a most *brilliant green* colour.

The phenomena of dichroism are seen also in *Sapphire*, *Idocrase*, and other minerals. See *Phil. Trans.* 1819, p. 22, 23; and *Edin. Phil. Journal*, vol. iii. p. 243.

Art. II.—*On the Absorption of Polarised Light by Doubly Refracting Crystals.*

If we take a prism of certain specimens of *Beryl* of a bluish-green colour, and examine it in every direction by common light, no change of tint appears, excepting that which arises from the different thicknesses through which the light is transmitted; but if we expose it to polarised light, we shall find that it transmits only a beautiful *blue* light when its axis is perpendicular to the plane of polarisation, and only a *greenish-white* light when the axis coincides with that plane; the transmitted light passing from the former to the latter tint, while the crystal is moving from the first into the second position. Hence it is obvious, that the *green* light is absorbed in one position, and the *blue* light in the other position. Now, this absorption varies with the angle which the polarised ray forms with the axis of the prism, being a maximum when that angle is 90°, and vanishing altogether when the ray passes along the axis.

If we now cut the crystal of beryl into a prism, so as to separate its two images, we shall find that these two images have different colours, the one having the same colour that would have been produced by exposing it in one position to polarised light, and the other image having the colour that would be obtained by turning it round 90°. Here, then, we have two singular properties of this class of crystals, which always appear to accompany one another, viz. the property which the extraordinary refracting force possesses of selecting certain rays out of the compound beam of common incident light, and the property of absorbing these rays in one position, and the supplementary rays in another position, when the incident light has been previously polarised.

The property which has now been described as belonging to *beryl*, Dr. Brewster has found in other twelve crystals with *one axis*. The colour of the ordinary and extraordinary images, or of the absorbed pencils, is shown in the following Table.

List of Absorbing Crystals with One Axis.

Names of Crystals.	Colour when its axis is in the plane of primitive polarisation.	Colour when its axis is perpendicular to that plane.
Zircon	Brownish white	A deeper brown
Sapphire	Yellowish green	Blue
Ruby	Pale yellow	Bright pink
Emerald	Yellowish green	Bluish green
Emerald	Bluish green	Yellowish green
Beryl blue	Bluish white	Blue
Beryl green	Whitish	Bluish green
Beryl yell. green.	Pale yellow	Pale green
Rock crystal, almost transparent	Whitish	Faint brown
Rock crystal yell.	Yellowish white	Yellow
Amethyst	Blue	Pink
Amethyst	Greyish white	Ruby red
Amethyst	Reddish yellow	Ruby red
Tourmaline	Greenish white	Bluish green
Rubellite	Reddish white	Faint red
Idocrase	Yellow	Green
Mellite	Yellow	Bluish white
Phos. of lime (lilac)	Bluish	Reddish
Phos. of lime (olive)	Bluish green	Yellowish green
Phos. of lead	Bright green	Orange yellow
Calcareous spar	Orange yellow	Yellowish white

The property which these crystals possess of absorbing the different tints in different positions of the axis, with regard to the plane of primitive polarisation, does not belong to every specimen. There are many crystals of ruby, sapphire, emerald, &c. which give an ordinary and an extraordinary image of the same colour; and whenever this is the case, they are destitute of the property of absorbing polarised light. These two classes of phenomena are indeed invariably connected, and will ultimately be found to have the same origin.

In crystals with two axes, the preceding phenomena receive some curious modifications; for a particular account of which we must refer to the *Phil. Trans.* 1819. The two colours which appear in the ordinary and extraordinary pencils are now seen diverging rectangularly from the resultant axes of the crystal; an effect which constitutes one of the finest appearances in optics.

The following Table contains the tints in several crystals, in which the effect will be seen in every azimuth.

List of Absorbing Crystals with Two Axes.

	Plane of the resultant axes in the plane of prim. polarisation.	Plane of the resultant axes perpendicular to the plane of prim. polarisation.
Topaz blue	White	Blue
—— green	White	Green
—— greyish blue	Reddish grey	Blue
—— pink	Pink	White
—— pink yellow	Pink	Yellow
—— yellow	Yellowish white	Orange
Sulphate of barytes —— yellowish purple	Lemon yellow	Purple
—— yellow	Lemon yellow	Yellowish white
—— orange yellow	Gamboge yellow	Yellowish white

	Plane of the resultant axes in the plane of prim. polarisation.	Plane of the resultant axes perpendicular to the plane of prim. polarisation.
Kyanite	White	Blue
Dichroite	Blue	Yellowish white
Cymophane	Yellowish white	Yellowish
Epidote olive green	Brown	Sap green
——— whitish gr.	Pink white	Yellowish white
Mica	Reddish brown	Reddish white

The following Table shows the characters of the tints in crystals with two axes, which have not been examined in every azimuth.

	Axis of prism in the plane of primitive polarisation.	Axis of prism perpendicular to the plane of primitive polarisation.
Mica	Blood red	Pale greenish yell.
Acetate of copper	Blue	Greenish yellow
Muriate of copper*	Greenish white	Blue
Olivine	Bluish green	Greenish yellow
Sphene	Yellow	Bluish
Nitrate of copper	Bluish white	Blue
Chromate of lead	Orange	Blood red
Staurotide	Brownish red	Yellowish white
Augite	Blood red	Bright green
Anhydrite	Bright pink	Pale yellow
Axinite	Reddish white	Yellowish white
Diallage	Brownish white	White
Sulphur	Yellow	Deeper yellow
Sulphate of strontites	Blue	Bluish white
——— cobalt	Pink	Brick red
Olivine	Brown	Brownish white

In the last eight crystals of the preceding Table, the tints are not given in relation to any fixed line.

The following Table contains the characters of the two pencils in crystals, the number of whose axes has not yet been determined.

Phosphate of iron	Fine blue†	Bluish white
Actynolite	Green	Greenish white
Precious opal	Yellow	Lighter yellow
Serpentine	Dark green	Lighter green
Asbestos	Greenish	Yellowish
Blue carb. of copper	Violet blue	Greenish blue
Octohedrite (*one axis*)	Whitish brown	Yellowish brown

Several of the preceding crystals which have a laminated structure, such as mica, epidote, &c. or such as have an imperfect transparency from a defective aggregation of their elementary crystals, frequently exhibit their absorptive qualities, and also their system of coloured rings, by exposure to common light. The light is, in these cases, analysed in passing obliquely through the laminæ, in the same manner as if it had been transmitted through a bundle of glass plates.

The absorbent power of crystals is modified in a very remarkable manner by heat, and this property may even be communicated to them by methods which are described in the paper already quoted. See *Phil. Trans.* 1819. p. 11. or *Edin. Phil. Journal*, vol. ii. p. 346.

Art. III.—*On the Absorption of Common and Polarised Light by the Oxidated Surfaces of Metals.*

The phenomena exhibited by the action of oxidated surfaces on common and polarised light, were first observed by Dr. Brewster in 1812.‡

When a ray of white light is reflected from an indigo-coloured oxide of steel, the reflected pencil contains two pencils, viz. *red* and *blue*, polarised in opposite planes, the *red* pencil being greatly inferior in intensity to the *blue* pencil. At an angle below 60° the blue pencil becomes more intense, and is a maximum at a perpendicular incidence; while below 60°, the *blue* pencil appears less and less brilliant.

When a ray of common light is reflected successively between two plates of this blue steel, the red rays are entirely absorbed, and the resulting pencil is of the most brilliant blue colour, and all polarised in the plane of reflexion. If the colour of the steel is *purplish red*, the resulting image of the successive reflexions will be *deep red;* and if the colour of the steel is straw-yellow, the resulting image will be a brilliant yellow, the light polarised perpendicularly to the plane of reflexion being uniformly absorbed.

If we take two plates of uncoloured steel, the same effect will be produced, only the resulting image will have no decided colours. The same is true of almost all the other metals, but the absorption is much less in gold and silver, especially the last, from which it requires a very great number of successive reflexions to extinguish one of the images.

The absorption of polarised light by oxidated and metallic surfaces is analogous to that of crystals, as already described, and may be deduced from the laws of metallic polarisation, to be given in a subsequent section.

Sect. X.—*On the Polarisation of Light by the Transmision of Heat through Glass and other Bodies.*

In all the phenomena of polarisation and double refraction, which we have hitherto considered, the power of producing these properties in bodies, was supposed to be derived from some unknown cause; and it was never conceived to be possible to communicate by art the polarising and doubly refracting structure to bodies that did not possess it.

In a letter addressed to Sir Joseph Banks, dated April 8, 1814, and read before the Royal Society on the 19th May, 1814, Dr. Brewster announced the discovery that a piece of glass received the doubly refracting and polarising structure in the process of being heated at a candle, and lost this property by cooling; and that Prince Rupert's drops possessed distinct, neutral, and depolarising axes, like the most perfect crystals.

In the year 1815 he instituted a regular set of experiments on the transmission of heat through glass, which were communicated during that year to the Institute of France, and to the Royal Society of London. The results of these experiments we shall now endeavour to explain as briefly and perspicuously as possible.

Art. I.—*On Circular Plates of Glass with one Axis of Polarisation.*

If we take a plate of glass, ACBD, Plate CCCCXXXVI. Fig. 8. perfectly cylindrical, and transmit heat from its circumference to its centre, we shall find that it will exhibit, when exposed to polarised light, and when the heat has reached its centre, the system of rings shown in the figure, traversed by a black rectangular cross AB, CD. This system of rings is precisely the same, both in appearance, and in the character of its tints, as the system seen along the axis of *zircon*, *ice*, and other crystals of the *positive* class.

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* The tints are given in relation to the short diagonal of its rhomboidal base.

† When the axis of the prism was in the plane of primitive polarisation.

‡ *Treatise on New Phil. Instruments*, p. 344.

If the circular plate of glass, on the contrary, is immersed in boiling oil, or equally heated in any other way, and is allowed to cool rapidly, it will exhibit a similar system of rings; but this system has a *negative* polarisation, like the rings formed by *calcareous spar*, *beryl*, &c. and other crystals of the *negative* class.

This opposition in the character of the two plates may be finely observed, by combining them together, as already described in page 725.

By comparing the value of the tints with their distances from the centre of the plate, Dr. Brewster found, that they vary as the squares of their distances from the axis. Hence if T is the tint which corresponds to any distance D, the tint t, corresponding to any other distance d, will be found by the formula

$$t = \frac{\mathrm{T}\, d^2}{\mathrm{D}^2}$$

Art. II.—*On Rectangular Plates of Glass with two Axes of Polarisation.*

Let a well annealed rectangular plate of glass EFCD. having no polarising structure, Fig. 25. be now placed with its lower edge CD upon a thick bar AB of red-hot iron, and exposed to polarised light in the usual way. The entrance of the heat into the glass at CD will be marked by fringes of coloured light at CD; and *nearly at the same instant, and before a single particle of heat has reached the upper edge* EF *or even* a b, *corresponding fringes will appear at* EF, and also at *a b*, and the fringes will become more distinct till they resemble those seen in Fig. 25. where MN, OP are two black lines, where there is neither double refraction nor polarisation. Between OP and MN the doubly refracting and polarising structure is *negative*, because the fringes descend in the scale when crossed by the axis of a plate of sulphate of lime; while the structures between OP and EF, and between MN and CD, are positive.

If the plate of glass is immersed in boiling oil, and then allowed to cool rapidly, it will exhibit the same fringes, &c.; but the central structure will now be *positive*, and the two external structures *negative*.

When heat is distributed uniformly over the plate, in both the preceding cases, the fringes are no longer visible. In all these cases, similar fringes and structures are seen through the thickness of the plates, and also in the direction of their length. When the plate of glass is nearly of a square form, and its thickness about one-third of the length of one of its sides, these fringes assume the form shown in Fig. 26; and when the length of the piece of glass is about three times that of one of the sides, the fringes have the form shown in Fig. 27.

All the tints displayed in these fringes resemble, in every respect, the tints polarised by doubly refracting crystals, and follow the same laws in their combination.

By measuring carefully the distances of the tints from the centre of the plate, Dr Brewster found the following formula, deduced from the supposition of two axes, perfectly correct, viz. $t = \mathrm{T} - \frac{\mathrm{T}\, d^2}{\mathrm{D}^2}$, where d, is the distance from $a\, b$ of the point at which the tint is required, and D the distance of either of the black fringes, or lines of no polarisation, from the centre of the plate. The term $\frac{\mathrm{T}\, d^2}{\mathrm{D}^2}$ represents the influence of the principal axis or series of axes, perpendicular to the plate, and would have given us the tint t if these axes had existed alone. But as the axis or series of axes in the plane of the plate produces an uniform tint T in every part of the plate, which acts in opposition to the other tint; the tint t must be equal to the difference of these tints, or to $\mathrm{T} - \frac{\mathrm{T}\, d^2}{\mathrm{D}^2}$, or if we make $\mathrm{T} = 1$, and $\mathrm{D} = 1$, we have $t = 1 - d^2$.

If we wish to find the tint, in terms of the distance of any point from the two black lines MN, OP, let δ, δ', represent the distances of any point from those lines whose distances from the centre was formerly d, then we have $\delta = 1 - d$, $\delta' = 1 - d$, and $\delta\,\delta' = 1 - d^2$; that is, the tint t, at any point, varies as the product of the distances of that point from the lines of no polarisation. If we call v the velocity of the extraordinary ray, and V that of the ordinary ray, we shall have $v^2 = \mathrm{V}^2 + a\,\delta\,\delta'$, a formula which represents the extraordinary refraction in rectangular plates of glass. In circular plates the expression becomes $v^2 = \mathrm{V}^2 + a\,\delta^2$

The effects now explained as produced in glass, are exhibited also during the propagation of heat through *rock salt*, *fluor spar*, *obsidian*, *semi-opal*, *rosin*, *copal*, *amber*, *and tortoise shell*, &c.

The properties of heat, which have just been described, suggested to Dr. Brewster the construction of a *chromatic thermometer*, which consists in combining a great number of plates of glass, to the edges of which the heat to be measured is applied. The coloured tints developed by the combined plates become a measure of the difference of temperature. This instrument will enable us to measure any temperature below that at which glass becomes red hot. The heat of the hand applied to a single plate of glass will develop a tint which may be distinctly appreciated by the eye, and, consequently, ten such plates would render perceptible the tenth part of the same degree of heat. See *Phil. Trans.* 1816, p. 108, for a full description of this instrument.

Art. III.—*On the Effect of combining and crossing Rectangular Plates of Glass of different kinds.*

If we *combine* a *positive rectangular plate*, or one in which the principal axis is *positive*, with another positive rectangular plate, so that the lines of no polarisation are parallel, the effect of each will be combined as if a plate had been used equal to the sum of their thicknesses, and the fringes on each side of the black lines will increase in number.

If we combine a *positive rectangular plate* with a similar *negative rectangular plate*, the effect of the one will counteract that of the other. If they have equal actions, the polarising structure of the one will destroy that of the other; but if they are unequal, the effect will be the same as if a plate had been used of the same thickness as the difference of their thicknesses, and having the structure of the thickest of the two combined plates.

When two positive, or *two negative* rectangular plates are crossed, as shown in Fig. 28. the tints are in some places raised in the scale, and in others depressed, according as opposite or similar structures are opposed to one another, the crossing of two positive or two negative structures sinking the tints in the scale, and the crossing of a positive with a negative structure raising them. By finding the tint at any given point in each plate from the preceding formulæ, and combining these tints according to the rule already given, it will be found that the *isochromatic curves* at the intersectional space ABCD are *hyperbolas*, which will be *equilateral* when the breadths and the maximum tints of the two plates are the same.

When a *positive rectangular plate crosses a negative plate*, it will be found, by the same process, that the isochromatic curves are *ellipses*, as in Fig. 29. when the plates are of unequal breadths; and that they become *circles* when the plates and maximum tints are equal, as in Fig. 30.

All these different phenomena were observed by Dr. Brewster, and are also deduced mathematically from the formula $t = 1 - d^2$, in his paper in the *Edinburgh Transactions*, vol. viii. p. 357.

Art. IV.—*On the Distribution of the Polarising Force in tubes of Glass.*

We have already seen, that *circular plates* or *cylinders* of glass, have *one positive axis*, like *zircon*; but when the cylinder has the form of a tube, like AB, Fig. 31. the polarising force is distributed in a very remarkable manner. A black circular fringe *m p n o* forms the line of no polarisation, and the coloured fringes are placed on each side of this dark ring, and concentric with it. The structure on the outside of *m p n o* is *positive*, like *zircon*, &c. and the structure on the inside *negative*, like *calcareous spar*.*

The breadth of the negative annulus, *a o* is always less than that of the positive annulus A o, the former decreasing, and the latter increasing, as the bore of the tube diminishes; and when the bore becomes extremely small, as in Fig. 32. the negative structure is also extremely small, and sometimes can scarcely be seen without the aid of a microscope.

In comparing the values of the tints with their distances from the line *m p n o*, Dr. Brewster has found that they vary as the distances. Hence it is obvious, that the glass is in a state of compression within the black ring *m p n o*, and in a state of dilatation without that ring, and that the particles are held in violent constraint, entirely different from that position of equilibrium in which they are placed in plates of glass with one or two axes.

If a tube of glass is brought to a red heat, and then cooled by inserting in its bore a cylinder of iron, or any other conducting body, the structure will then be the same as is represented in Fig. 33.

If a solid cylinder of glass which has only one structure, is perforated in its centre, it will exhibit the appearance in Fig. 31.

When polarised light is transmitted through a long cylinder of unannealed glass, in a line perpendicular to its axis, after it is immersed in a fluid of the same refractive power, it exhibits the same phenomena as rectangular plates of glass, having a positive axis perpendicular to its length, and a negative axis perpendicular to the positive one; but in the cylinder, the external tints do not rise so high, from the diminution in the thickness of the glass towards the edge.

The same phenomena are exhibited by a glass tube, but the maximum tint does not appear along the central axis of the tube, but on each side of it,—an effect obviously occasioned by the greater thickness of the glass in these directions.

In examining the structure of glass tubes, it will be found that they are, as it were, divided into different elementary concentric tubes; and that in some cases there is an actual separation between them. Hence there arises a singularity in the progression of the tints. Instead of shading into one another, each elementary tube has an uniform tint of its own, as is represented in Fig. 34. where the tube ACBD is divided into four tubes 1, 1; 2, 2; 3, 3; 4, 4; the tube 4, 4, is in every part of it a *white* of the first order; the tube 3, 3, is every where equally dark, being the black circular fringe *m p n o* of Fig. 32; the tubes 2, 2, and 4, 4, are a *white* of the first order; and the tube 1, 1, is a *yellow* of the first order. Hence it follows, that in tubes which possess this peculiarity of structure, each elementary tube is uniformly dense throughout, and that the variation of density takes place by leaps.

Art. V.—*On the effects produced by subdividing, or altering the form of, Plates and Cylinders of Glass.*

If we make a cut with a diamond across the line *a b* of a plate of glass CDEF, Fig. 25. and having placed it on the hot iron AB, break it into two pieces when the fringes are fully developed, we shall find that *each half of the plate has the same structure as the whole plate had before*. The heat, whose unequal distribution producing an inequality of density, (according to a certain law indicated by the progression of the tints,) has its distribution instantaneously altered, and a portion of it escapes during the change. This effect, which is one of the most singular facts in natural philosophy, is shown in Fig. 36. which represents the arrangement of the tints, when the glass is divided along the line *r s*, each plate having two lines of no polarisation, and *one negative*, between *two positive* structures, exactly like the primitive plate before it was divided. If the plate had been divided in the direction CD, the angular fringes will start up at the two new angles which are formed by the division of the plate.

This experiment may be performed in a still simpler manner, by taking two separate plates of glass, EF *s r*, GH *s r*, Fig. 36. When these plates are pressed together with the force of a screw, and then laid with the edge GH on a plate of hot iron, the heat will distribute itself as if the whole constituted one plate, and produce the effect shown in Fig. 25; but the moment the plates are separated, the heat will distribute itself as in Fig. 36.

When the tints are arranged in a glass cylinder, as in Fig. 31. take a file with a very sharp edge, and cut the tube entirely through by a notch EF, Fig. 33. By this operation the particles will be freed from the state of violence in which they are held, and will assume the very same arrangement which they never fail to take in rectangular plates of glass. By exposing the tube, thus divided, to polarised light, it will exhibit the appearance shown in Fig. 33. where $m\,p\,n\,o$, $m'\,p'\,n'\,o'$, are two dark fringes having a negative structure on the outer side of each, and a positive structure between them, as in plates of glass with two axes. The same result will be obtained with a tube of a very large bore, having its exterior diameter 0.875 of an inch, and its interior diameter 0.816; so that the thickness of the glass was only 0.059 of an inch. When the tube is cut into two or more pieces, each piece has the same structure as a plate of glass with two axes. By a number of measurements, Dr. Brewster found that the diameter $o\,p$, Fig. 31. of the black fringe or circle of no polarisation, is a geometrical mean between the interior and exterior diameters of the tube; that is,

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* In the *Edinburgh Transactions*, vol. viii. p. 362, from which these remarks are taken, the words, "negative like calcareous spar," and "positive like quartz," should be transposed; and in the same page, and in p. 363, *positive* and *negative* should also be transposed, as the reader will readily discover.

$$o\,p = \sqrt{\overline{AB \times a\,b}}.$$

If we take a piece of unannealed glass, perfectly circular, we have only one axis, or one structure, as shown in Fig. 8. But if we grind the smallest quantity from any two opposite sides CB, AD, so as to induce a slight degree of ellipticity, a new axis is created; the tint which it produces appears at the centre of the plate, and the system of rings has the form shown in Fig. 35, where the internal structure within the black fringes AD, CB, is negative, and the two external structures without AD, CB, positive.

If, on the contrary, we now grind a small quantity from the sides AC, BD, so as to reconvert the elliptical plate into a circular plate, we shall find that the new axis, which was generated by the change of form, has entirely disappeared, so that the plate exhibits the figure shown in Fig. 8.

For further information on the subject of this section, see the *Philosophical Transactions*, 1816, p. 46; and the article HEAT, vol. x. p. 677.

SECT. XI.—*On the Polarisation of Light by Plates of Glass permanently crystallized.*

In the month of March, 1814, Dr. Brewster found that glass melted and suddenly cooled, as in Prince Rupert's drops, displayed all the phenomena of doubly refracting and polarising crystals, and had, in the most distinct manner, regular neutral and depolarising axes.

Dr. Seebeck published, in Schweigger's Journal for Dec. 1814, an account of a series of experiments, in which he had communicated the polarising structure permanently to plates of glass, by making them red-hot, and then cooling them gradually; and, in the summer of 1815, Dr. Brewster discovered the same method, after he had made all his experiments on the transmission of heat through plates of glass.

In order to make these plates, we have only to bring them to a red heat, and cool them as rapidly and equally as possible, by placing a conducting substance in contact with all the edges of the plates. When the plates are cold, they will exhibit the same fringes which are produced during the transmission of heat, and which are shown in Fig. 25.

The *negative* plates with one axis, and the rectangular plates with the principal axis negative, cannot be produced by this method.

The following table shows the tints developed by rectangular plates of glass of different thicknesses, and which were cooled by placing only one of their edges upon a piece of cold iron.

Thickness of the Plates.	Maximum Tint at the Lower Edge at CD, Fig. 25.	Tint in the Middle, or the Line $a\,b$, Fig. 25.	Numbers in Newton's Table corresponding to the Maximum Tint.
0.1125	Beginning of *Blue* of 2d order.	*Blue* of the 1st order.	8.7
0.2000	*Green* of the 3d order.	Beginning of *Blue* of 2d order.	16.2
0.2666	Bluish *Green* of the 4th order.	*Blue* of 2d order.	22.0
0.2833	*Green* of the 4th order.	Beginning of *Purple* of 1st order.	22.7
0.4375	End of *Red* of the 5th order.	*Black* of the 2d order.	35.5

For farther information on this subject, see *Phil. Trans.* 1816, p. 78.

SECT. XII.—*On the Polarisation of Light by Evaporation and Gradual Induration.*

The earliest experiment on this branch of our subject was made by Dr. Brewster, in the beginning of 1814.* He observed that when caoutchouc was dissolved by heat, and had no action upon light, it acquired the polarising structure after standing a certain number of days.

The same effect was likewise produced by the gradual induration of calves' foot jelly,† and the phenomena were afterwards more fully developed in parallelopipeds of jelly and isinglass. Our limits, however, will not allow us to enter into any details on the subject, and we must, therefore, refer the reader to the *Phil. Trans.* 1814, p. 2, 3; 1815, p. 61; and 1816, p. 172.

SECT. XIII.—*On the Communication of the Polarising Structure by Compression and Dilatation.*

On the 3d of January, 1815, Dr. Brewster discovered that soft animal substances, such as calves' foot jelly and isinglass, acquire from simple pressure that peculiar structure, which enables them to form two images polarised in an opposite manner, like those produced by all doubly refracting crystals, and to exhibit the complementary colours produced by regularly crystallized minerals. This remarkable effect was observed in a cylindrical piece of tender calves' foot jelly, which could scarcely support its own weight, and which had no action whatever upon polarised light; but whenever it was pressed in the slightest manner between the finger and the thumb, or even touched gently by the finger, it instantly displayed the properties of the polarising structure.

During some subsequent experiments on this subject, in October, 1815, the same author observed that com-

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* See *Phil. Trans.* 1814, p. 8. 31.

† *Phil. Trans.* 1815, p. 61, &c.

pression produced a *negative* polarising structure, and *dilatation* a *positive* polarising structure; and by dilating isinglass, he created a polarising structure much more powerful than that which is possessed by Beryl.

These experiments, which had hitherto been confined to a soft solid, he extended, on the 1st November, 1815, to plates of solid glass; but finding it difficult to apply regular forces to such a hard substance, so as to develop regular effects, and ascertain the laws of the phenomena, he conceived the idea of developing the polarising structure, by *bending plates of glass, whose edges were ground and polished.* In this way he succeeded in developing the phenomena in the most simple manner.

If we take any slip of glass, cut merely with a diamond, and holding one end of it in each hand, bend it slightly, we shall observe, through its edges, when exposed to polarised light, two separate structures AB, CD, Fig. 2. separated by a dark line MN; and each of them covered with coloured fringes, the scale of which commences at MN. When the axis of a plate of sulphate of lime is made to cross these fringes, those in CD, on the concave side, will rise in the scale, and will therefore be *positive*, while those in AB, on the convex side, will fall in the scale, and will therefore be negative. By measuring the breadth of the fringes, the tints were found to vary as their distance from the axis.

When two bent plates of glass cross one another at right angles, as shown at Fig 1. the intersectional fringes are *straight lines* parallel to *m n*, the line of no polarisation.

When a plate of bent glass CD, Fig. 3. is made to cross a plate of glass, AB, crystallized permanently by rapid cooling, the intersectional fringes will be *parabolas*, whose vertices will be towards the convex side, if the principal axis of AB is *positive*, as in the figure, but towards the concave side, if the principal axis of AB is *negative*.

The doubly refracting structure may also be communicated to *rock salt*, *fluor spar*, *diamond*, *amber*, *copal*, *caoutchouc*, *rosin*, *phosphorus*, and other substances.

By the application of compressing and dilating forces, Dr. Brewster succeeded in altering the polarising structure of regularly crystallized bodies in every direction; but the effect, as might have been expected, was always most obvious when it was produced along the real or the resultsnt axes, where the natural doubly refracting force was a minimum.

By using plates of crystals, and applying the forces to parallel surfaces, he obtained the following results:

		Axes of Compression, or Dilatation parallel to the Axis of the Crystal.	Axis of Compression, or Dilatation perpendicular to Axis of Crystal.
Positive crystals	Compressed	Tints rise	Tints descend
	Dilated	Tints descend	Tints rise
Negative crystals	Compressed	Tints descend	Tints rise
	Dilated	Tints rise	Tints descend

For farther information on this subject, see *Phil. Trans.* 1816, p. 156; and *Edin. Trans.* vol viii. p. 281.

SECT. XIV.—*On the Polarisation of Light by Metals.*

When Malus published his discovery of the polarisation of light by reflexion, he announced that the metals polarised light in a very imperfect manner; but upon resuming the investigation, and examining the action of metallic surfaces upon polarised light, he found that, when the plane of reflexion from the metal was inclined about 45° to the plane of primitive polarisation, the polarised ray was depolarised by the metal, which could only be effected by the power of producing two oppositely polarised images. When the plane of reflexion was either parallel or perpendicular to the plane of primitive polarisation, the polarised ray suffered no change. Hence Malus concluded, that while transparent substances refract all the light polarised in one plane, and reflect all the light polarised in the opposite plane, metallic bodies reflect what they polarise in both planes.*

In examining the effects produced by successive reflexions from metallic surfaces, Dr. Brewster discovered that they possessed the singular property of producing, when exposed to polarised light, the phenomena of the complementary colours, and of moveable polarisation, like crystallized bodies.

Let us suppose that two parallel plates of highly polished silver, about three or four inches long, and half an inch broad, are fixed at the distance of about half an inch, and are interposed at *e f*, Plate CCCCXXXVI. Fig 4. between the polarising plane AB, and the analysing plate CD, and that the silver plates can be turned round, that the plane of reflexion may form any angle with the plane of primitive polarisation AST. If the plane of reflexion from the silver plates, is either parallel or perpendicular to the plane of primitive polarisation, the action of the plates upon the polarised ray will be nothing, that is, the ray will retain its primitive polarisation, and will be colourless, however great be the number of reflexions. In every other position, however, of the plane of reflexion from the silver plates, and at every angle of incidence, the polarised ray will be divided into two portions, O and E, one of which, O, retains its primitive polarisation, while the other, E, is polarised in an angle equal to 2 *a*, or twice the azimuth of the plane of reflexion. When *a* is 45°, the tint E is a maximum, just as in plates of regularly crystallized bodies; the azimuthal angle of the plane of reflexion in the former replacing the azimuth of the axis in the latter.

When a polarised ray is reflected from a single metallic surface in the manner now described, it experiences the same modification, as if it had passed through a plate of any crystallized body of a certain thickness. If the action of the metallic surface is combined with that of a plate of sulphate of lime, having its axis coincident with the plane of reflexion, the colour polarised by the system will be that which is due to the sum of the thicknesses of the crystallized plate, and the equivalent plate of the same substance; but if the axis of the plate is at right angles to the plane of reflexion, the colour polarised by the system will be that which belongs to the difference of the thicknesses of the crystallized plate and the equivalent plate. The same is true of two or more metallic reflexions, each reflexion being equivalent to a plate of a crystallized body of a given thickness, their thickness varying with the angle of incidence; and if the angle of incidence varies, the thickness of the equivalent plate always increases as the angle of incidence upon the metal diminishes; or the depth to which the incident ray penetrates the metallic surface, increases as it approaches to the perpendicular.

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* The polarisation of light by metallic bodies was discovered by Dr. Brewster before he knew that Malus had resumed the consideration of this subject. See *Treatise on New Phil. Inst. Pref.* p. xiii. xiv. and p. 347.

The same effect is produced by successive reflexions from *Gold*, and, in an inferior degree, from *Platinum*, *Steel*, *Brass*, *Copper*, *Tin*, *Lead*, *Mercury*, *metal for specula*, and *Amalgam of Bismuth*.

When a ray of *common light* has suffered a number of reflexions from polished plates of silver, Dr. Brewster found, that even when the number of reflexions was thirty-six, the emergent pencil consisted of two pencils polarised in opposite planes. A portion of the most refrangible rays was absorbed at each reflexion, so that the resulting pencil was of a *deep red* colour. As one of the images was decidedly fainter than the other, the pencil would have ultimately been all polarised in the plane of reflexion. Hence it follows, that the intensity of the pencil polarised in the plane of reflexion is greater than that of the pencil polarised in the opposite plane; but these two intensities approach nearer to equality in silver than in any other metal.

If common light is incident upon *Steel*, and all the other metals except *Gold* and *Silver*, *five* or *six* reflexions at an angle of 70° are sufficient to polarise the whole of the incident pencil in the plane of reflexion. Hence it follows, that in all these metals the pencil polarised in the plane of reflexion exceeds greatly in intensity that which is polarised in an opposite plane; a great portion of this last pencil having been absorbed by the substance of the metal.

The first experiments of Dr. Brewster were repeated by M. Biot, who obtained also several similar results. A full account of the history of this branch of the subject will be found in an early number of the *Edinburgh Philosophical Journal*. M. Biot's account of the subject will be found in his *Traité de Physique*, tom. iv. p. 579.

SECT. XV.—*On the Polarisation of Light by Total Reflexion from the Second Surfaces of Transparent Bodies.*

The discovery of the polarisation of light in two opposite pencils by the action of the forces which produce total reflexion, was made by Dr. Brewster in 1814, and explained in his paper on the Polarisation of Light by Reflexion.

The experiments by which he ascertained this property were conducted in a manner similar to those of Malus upon polished metals. A ray of polarised light was found to be depolarised by total reflexion, when the plane of total reflexion was inclined 45° to the plane of primitive polarisation, and in intermediate degrees at different azimuthal angles, excepting when the azimuths are 0°, 90°, 180°, and 270°, or when the plane of total reflexion is parallel or perpendicular to the plane of primitive polarisation.

During these experiments, Dr. Brewster likewise discovered that the complementary colours of moveable polarisation were produced by total reflexion in a manner analogous to those produced by metallic surfaces; one reflexion appearing to correspond to an equivalent plate of a crystallized body of a certain thickness. The effect is increased by increasing the number of reflexions in the same plane; but when the two reflexions are in planes at right angles to each other, the actions counteract each other. These effects he attributed to the circumstance of one of the pencils being later in suffering reflexion than the other, the first being under the influence of the force that produces the usual partial reflexion, and the other, after beginning to be refracted, being caused to return by the continued operation of the same power. This idea, which he communicated to Dr. Young, as supporting his ingenious theory of recurrent colours, was afterwards adopted by that eminent author.

In the year 1816, Dr. Brewster undertook a set of experiments on a large scale, on the effects produced by total reflexion; and in the same year he announced in the journals that a new kind of moveable polarisation was produced. These experiments, which prove that the total reflexion communicates properties to polarised light different from those of ordinary polarisation, were signed by the President of the Physical Class of the Royal Society of Edinburgh, but have not yet been published.

The fine discovery of M. Fresnel, that the phenomena of circular polarisation may be produced by the combination of total reflexions in opposite planes with the ordinary polarising action of crystals has already been explained in Sect. vi. p. 732.

SECT. XVI.—*On the Action of Crystallized Surfaces upon Light.*

It has been remarked by Malus, "that the action which the first surface of Iceland spar exercises upon light, is independent of the position of its principal section; that its reflecting power extends beyond the limits of the polarising forces of the crystal, and that, as light is only polarised by penetrating the surface, the forces which produce extraordinary refraction begin to act only at this limit." He also observes, that "the angle of incidence at which Iceland spar polarises light by partial reflexion, is 56° 30′; that it then comports itself like a common transparent body; and that, whatever be the angle comprehended between the plane of incidence and the principal section of the crystal, the ray reflected by the first surface is always polarised in the same manner."*

In order to examine with care the superficial action of calcareous spar, Dr. Brewster exposed several surfaces by cleavage, and having selected the one that had the most perfect polish, he covered all the other sides of the rhomb with black wax, and measured the polarising angles in planes variously inclined to the principal section. The following are the results of a great number of observations:

Position of the crystal.	Azimuth.	Polarising angle.	No. of observations
Short diagonal in plane of reflexion	0°	57° 14	39
One of the edges in plane of reflexion	50 57½′	58 32	15
Long diagonal in plane of reflexion	90	59 32	37
Difference between the greatest and least polarising angles		2° 18′	

The following observations were made with rhombs taken from a different mass of calcareous spar:

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* *Théorie de la Double Refraction*, p. 240, 241, and Biot's *Traité de Physique*, tom. iv. p. 339.

Position of the crystal.	Azimuth.	Polarising angle.	No. of observations.
Short diagonal in plane of reflexion	0°	57° 36′	5
One of the edges in plane of reflexion	50 57½′	58 50	7
Long diagonal in plane of reflexion	90	59 44	7
Difference between the greatest and least polarising angles		2° 8′	

In these experiments the results were the same, whether the obtuse angle of the rhomb was nearest or farthest from the eye, or whether it was to the right or left hand of the observer.

In order to determine the angle of polarisation for surfaces differently inclined to the axis, he selected some fine Faroë crystals of calcareous spar from the cabinets of Sir George Mackenzie and Mr. Allan. One of these crystals was an acute dodecahedron, having a highly polished surface inclined about 5° to the axis, and with it he obtained the following results.

Position of the crystal.	Polarising angle.	No. of observations.
Axis in plane of reflexion . .	54° 18′	13
Axis perpendicular to plane of reflexion	58 14	10

In any given surface of the rhomb, where A and A″ are the minimum and maximum polarising angles, viz. in the azimuth of 0° and 90°, the polarising angle A′, at any intermediate azimuth α, may be found by the formula

$$A' = A + \text{Sin.}^2\, \alpha\, (A'' - A.)$$

In the rhomboidal surfaces of calcareous spar,

$$A'' - A = 138'.$$

Since the extraordinary force in calcareous spar was thus shown to extend to such a distance beyond the surface as to modify the polarising angle produced by superficial reflexion, it became extremely probable that the polarisation of the reflected ray might suffer some change from the same cause: Dr. Brewster accordingly introduced a film of oil of cassia between a glass prism and the surface of the spar. and having inclined the prism at a very small angle to that surface, he thus separated the image formed at the common surface of the prism, and the oil from the image formed at the common surface of the oil and the spar. The effect was exactly what he had anticipated The influence of the ordinary reflecting force was reduced almost to nothing, and the light reflected from the separating surface of the oil and the spar, was polarised at an angle of about 45½°, and was almost entirely under the dominion of the force which emanated from the axis. The following were the results obtained with an ordinary surface, inclined 45° 23½′ to the axis.

1. *Azimuth* 0°. When the plane of the principal section is in the plane of reflexion, the light reflected at the surface of the oil and the spar is polarised in the plane of reflexion, the obtuse solid angle being farthest from the eye. The light of the image is of a faint red colour, and has very little intensity.

2. *Azimuth* 12°. The obtuse angle being farthest from the eye, the reflected pencil is polarised about 45° out of the plane of reflexion.

3. *Azimuth* 42°. The reflected pencil is polarised transverse to the plane of reflexion, or 90° out of it. The light is now of a yellowish white tint, and is much more intense than in azimuth 0°.

4. *Azimuth* 90°. When the plane of reflexion is perpendicular to the plane of the principal section, the obtuse solid angle being either to the right or left hand, the reflected pencil is polarised a little more than 135°, or—45° out of the plane of reflexion. The intensity of the pencil is now intermediate between that of azimuth 0° and 45°.

5. *Azimuth* 180°. The obtuse angle being now next the eye, the pencil is polarised 180° out of the plane of reflexion, or it has again returned into that plane.

In passing through the last 45° of azimuth, the polarisation varies very slowly, the change being only about 10°: whereas, in passing through the first 42° of azimuth, the polarisation varies no less than 90°, indicating in the most unequivocal manner, as we shall afterwards see, that this change depends upon the angle which the incident ray forms with the axis of the crystal. In the course of these experiments many other unexpected results were obtained; but we must refer the reader to the *Phil. Trans.* 1819, p. 145, &c. for a fuller detail of them.

The light reflected from the separating surface of the *oil* and the *spar* is a *maximum*, when the plane of the principal section is perpendicular to the plane of reflexion, and its colour is then nearly white. When these two planes coincide, the intensity of the light is a *minimum*, and its colour is then a faint red; and in intermediate positions, the reflected pencil has both its intensity and its colour of an intermediate character. In the azimuth of 42°, the reflected pencil exhibits a very curious phenomenon when analysed with calcareous spar. Its colour is then yellowish white, and all the *yellow* light is polarised transversely to the plane of reflexion. One of the images, however, instead of vanishing, consists of *blue* and *red* light, the *red* vanishing, and the *blue* becoming more brilliant as the analysing prism is turned to the *left*; and the *blue* vanishing, and the *red* becoming more brilliant as the prism is turned to the *right*. This effect arises from the difference in the angles at which the red and blue rays are incident upon the separating surface of the oil and the spar. Each set of rays, therefore, as will afterwards appear, suffers a different change of polarisation; the one being polarised about 87° out of the plane of reflexion, and the other 92°.

Dr. Brewster repeated the preceding experiments, by substituting, in place of oil of cassia, *water*, *alcohol*, *castor oil*. *balsam of capivi*, and *oil of anise seeds*, a series of fluids whose refractive powers increase progressively. With *water*, the light refuses to be polarised completely in the direction of the long diagonal, while it suffers complete polarisation in the direction of the short diagonal. With *alcohol*, the direction of the polarisation is not altered. With *castor oil*, the intensity of the light is greater in the direction of the long diagonal than in that of the short one; and in the former case, the pencil is polarised at a much greater angle than in the latter. With *balsam of capivi*, in the azimuth of 45°, the pencil is polarised about 15° out of the plane of reflexion. In the azimuth of 90°, the pencil is not completely polarised at any angle, but is nearly so in the plane of reflexion, and at a considerable angle of incidence. In 0° of azimuth. the pencil is completely polarised in the plane of reflexion. With *oil of anise seeds*, in azimuth 45°, the pencil is polarised about 45° out of the plane of reflexion. In azimuth 90°, the pencil refuses to be polarised at any angle, and in 0° of azimuth, the polarisation is complete in the plane of reflexion.

As the preceding results were obtained with a surface inclined 45° 23½′ to the axis, Dr. Brewster was anxious to observe the effects produced by the Faroë crystals, where the natural faces are nearly in the plane of the axis. He accordingly repeated the experiments with a variety of these crystals, and in every case he observed the same phenomena. In the azimuth of 90°, where the polarising angle is 58° 14′, the pencil was polarised a degree or two out of the plane of reflexion. In the azimuth of 45°, where the polarising angle is about 56° 16′, the change of polarisation is about 40°; and in the azimuth of 0°, where the polarising angle is 54° 18′, the change of polarisation was a little more than 90° when the obtuse angle was farthest from the eye, and about 106° when the obtuse angle was nearest the eye. In all these positions, the image reflected from the surface of the oil and the spar, is nearly as bright as that from the surface of the prism and the oil.

In order to determine the change of polarisation when the plane of reflexion was perpendicular to the axis, it was necessary to have a prismatic crystal of calcareous spar with a polished summit; but he always found this summit rough and unpolished. There was, therefore, no alternative but to polish an artificial face cut in this direction; and upon the application of oil of cassia, he found that in every azimuth the change of polarisation was about 75°. The colour of the image was a bright yellow, and a little blue light remained at the point of evanescence.

In extending these experiments to other crystals, our author obtained similar results; but there are none so well fitted for this species of examination as calcareous spar. In applying oil of cassia to a very fine prism of chromate of lead, the direction of the polarisation was not in the slightest degree altered, as the ordinary action was not sufficiently weakened to render visible the influence of the interior force. When the plane of reflexion passed through the axis of the prism, *blue* light remained in the vanishing image; but in a plane rectangular to this, the light was completely polarised, as in the experiment when the reflecting surface was in contact with air.

Dr. Brewster now tried *rock crystal* and *oil of anise seeds*, which have nearly the same mean refraction; but on account of the great debility of the interior polarising force, it was not able to overpower or even to modify that which accompanies partial reflexion. He could easily have reduced this last force still farther, till it came under the dominion of the first: but the reflecting power would have been reduced in the same proportion, and would not have been capable of driving back a number of rays sufficient to form a perceptible image. But though the polarisation is not changed at the separating surface of the oil and the rock crystal, yet the character of the reflected light is modified in a very remarkable manner. When the plane of reflexion from one of the sides of the prism of rock crystal was in the direction of the axis, or in 0° of azimuth, the reflected image was a *deep blue* of very little intensity; whereas, in a rectangular direction, where the azimuth was 90°, it was of a brick red colour, and much more luminous. On one of the faces of the pyramid, in azimuth 0°, the tint was a *brilliant pink*, intermediate between the *red* and the *blue*; and on the same face, in 90° of azimuth, it was of a *brick red* colour, as before. These variations are obviously related to the axis of double refraction, and indicate the extension of its force within the sphere of partial reflexion. The origin of the colours themselves, Dr. Brewster will soon have occasion to explain, in a paper on the action of uncrystallized surfaces.*

3. *General results deduced from the preceding experiments.*—Had it been in our author's power to command a series of the most perfect crystals, or to communicate to artificial faces that high polish which nature often exhibits, he might have obtained a more complete generalization of the preceding phenomena. Limited, however, as the investigation has been by these causes, it still presents us with several views of great generality and interest.

1. The force of double refraction and polarisation extends without the surface of crystals, and within the sphere of the force which produces partial reflexion.

2. The change in the angle of polarisation, produced by the interior force, depends on the inclination of the reflecting surface to the axis of the crystal, and also on the azimuthal angle which the plane of reflexion forms with the principal section.

3. The change in the direction of the polarisation must be produced after the ray has suffered reflexion; for if the change preceded reflexion, the reflecting force would have polarised it in the plane of reflexion, whatever had been the direction of its previous polarisation.

4. The change in the direction of the polarisation depends upon the angle which the incident ray forms with the axis of the crystal, and takes place in such a manner, that if

$\phi =$ angle of incident ray with the axis; and

$C =$ change in the direction of the polarisation,

we shall have $\text{Sin.}\ \tfrac{1}{2} C = \sqrt{\text{Sin.}\ \phi}$.

If we make

$A =$ complement of the inclination of the reflecting plane to the axis;

$\alpha =$ azimuth of the plane of incidence with the principal section; and

$i =$ angle of incidence reckoned from the perpendicular, we shall have

$$\text{Cos.}\ \alpha \times \text{Tang.}\ A = \text{Tang.}\ z, \text{ and}$$

$$\text{Cos.}\ \phi = \frac{\text{Cos.}\ A \times \text{Cos.}\ (i \pm z)}{\text{Cos.}\ z}.$$

In one of the ordinary rhomboidal surfaces, where the inclination to the axis is 45° 23½′, $A = 44° 36½′$; and with oil of cassia i, or the incidence of the mean ray, when the polarisation is complete, is about 45° 17′. Dr. Brewster assumed it at 45° 23½′, (which will be more correct for the mean luminous ray than 45° 17′,) for the purpose of making the change of polarisation commence with zero in 0° of azimuth.

Upon these principles, he computed the following table, which shows the change in the direction of the polarisation, corresponding to any azimuth and any inclination of the incident ray with the axis.

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* This paper was read before the Royal Society of Edinburgh, on the 4th of January, 1819.

Table showing the Change in the Direction of the Polarisation in different Azimuths.

Azimuth.	Inclination of Incident Ray to the Axis.	Change in the Direction of the Polarisation.
°	° ′	° ′
	0 0	0 0
10	6 54	40 36
20	16 50	65 6
30	23 0	77 22
40	29 24	88 52
45	32 38	94 34
50 57½′	36 29	100 54
60	42 17	110 10
70	48 32	120 0
80	54 37	129 8
90	60 0	137 0
100	65 56	145 48
110	71 4	153 4
120	75 42	159 48
129 2½′	79 28	165 3
135	81 41	169 46
140	83 22	170 34
150	86 12	174 52
160	88 18	177 36
170	89 33	179 28
180	90 0	180 0

The results in the preceding table, enable us to explain the phenomenon described in p. 744. As the interposed oil of cassia has a prismatic form, and a very high dispersive power, the blue and the red rays are incident at different angles with the axis, and therefore the change in the direction of their polarisation must be different. The nearest approximation to evanescence in one of the images, belongs to the mean ray of the spectrum, and therefore at this point the image that should have vanished, must consist of blue and red light, one of which colours will disappear *before*, and the other *after* the mean ray. See *Phil. Trans.* 1819, p. 145.

SECT. XVI.—*On the Phenomena of Tesselated Crystals.*

In all the crystals which have hitherto come under our notice, every portion of the crystal had the same property as the whole, and the forces of double refraction and polarisation had the same character and the same intensity in all parallel directions. A very singular exception to this general law presented itself to Dr. Brewster, while he was examining the Apophyllites of Faroë.

When we remove the uppermost slices A, B, Fig. 4, from each of the two summits of the crystal, to the thickness of the 100th of an inch or more, and examine it either by the microscope or by polarised light, we perceive no tesselated structure, and this slice has only *one axis* of double refraction. A number of veins appear at the edges MO, ON, NP, PM, as shown in Fig. 5. or at A, Fig. 4.

If we now remove the next slice, and all subsequent slices, we shall find that they exhibit by polarised light, and also by the microscope, under favourable circumstances of illumination, the beautiful figure represented in Figs. 4. and 5. The outer case MONP, Fig. 5. which binds the interior parts together, is composed of a great number of parallel veins, which, from their minuteness, display the colours of striated surfaces. This external coating envelopes no fewer than *nine* separate crystals, viz. the central lozenge *a*, *b*, *c*, *d*, which has *one axis* of double refraction; the four prisms A, B, C, D, with trapezial bases, which have *two axes* of double refraction; and the four triangular prisms *e h l*, *l m n*, *n k g*, *g f c*, all of which are separated from one another by distinct veins. The inflected lines *e h l*, *l m n*, *n k g*, *g f e*, are most easily seen by the microscope. The central lozenge is seen much less frequently, and the radial lines *h a*, *c k*, *f d*, *b m*, require a particular mode of illumination to be distinctly recognised, though they are easily seen by polarised light. In the quadrants AM and DN, the planes of the two resultant axes are coincident, and in the line MN; and in like manner in the quadrants BO, CP, the plane of the axes is in the line OP. The consequence of this is, that when a plate of sulphate of lime has its axis coincident with MN, it depresses the tints in A and B, and raises the tints in C and D, while the central lozenge and the radial lines have the same tint as the plate of sulphate of lime.

Among the peculiarities of apophyllite, there is none more remarkable than the variation which takes place in the intensity of the doubly refracting and polarising forces in the same crystal. This effect is well seen in the summit of one of the pyramidal crystals shown in Fig. 6. where the isochromatic lines, instead of being parallel to one another, as they would have been, had the polarising forces been uniform, undergo the most remarkable variation.

One of the Faroë varieties of apophyllite which occurs in complete and transparent crystals, exhibits through both its pairs of parallel faces the very remarkable tesselated structure shown in Fig. 7. consisting of the most splendid tints, arranged symmetrically in relation to the centre of the crystal. The existence of the curvilineal solid in the centre;—the gradual diminution in the length of the circumscribing plates, in consequence of which they taper, as it were, from the angles of the central square, to the truncated angles at the summits; but, above all, the reproduction of similar tints on each side of the central figure, and at equal distances from it, cannot fail to strike the observer with surprise and admiration.

The tints exhibited by each crystal vary, of course, according to its thickness, but the range of tint in the same plate, and at the same thickness, generally amounts, in the largest crystals, to three of the orders of colours in Newton's scale. The central portion, and the two squares, have, in general, the same intensity, while the four segments round the central portion, and some of the parts beyond each of the squares, are also isochromatic.[*] In the central part, the colours have a decided termination; but towards the summits of the prism their outline is less regular, and less distinctly marked; though this irregularity has also its counterpart at the other termination.

In order to ascertain the order of the colours polarised by the crystal, Dr. Brewster transmitted the polarised light in a direction parallel to one of the diagonals of the quadrangular prism, and thus obtained, as it were, a section of the different orders of colours, from the zero of

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[*] In some crystals the two smaller green segments have a different tint from the two larger segments, and the same tint as the central square.

their scale. The result of this experiment, shown in Fig. 8. displayed to the eye the law according to which the intensity of the polarising forces varied in different parts of the crystal. At the points in the diagonal $m n$, opposite to a and b of the crystal, the tints rose to the *seventh* order of colours; at other two places, opposite to c and d, they rose only to the *sixth*; while near the summits, at m and n, they descended so low as the *fourth* order. Hence it follows, that the portions at a, a, have the maximum polarising force; that the four segments round the centre, in Fig. 4. are next to these in intensity; that the central portions and the red squares are again inferior to these; and that the weakest polarising force is near the summits of the prism. At a and b, the fourth, fifth, and sixth fringes have a singularly serrated outline, exhibiting, in a very interesting manner, the sudden variation which takes place in the polarising forces of the successive laminæ. There is another variety of apophyllite brought by Sir Charles Giesecké from Disco, and called the Barrel Apophyllite, which exhibits, by polarised light, the singular structure represented in Fig. 9.

The tesselated structure has been found also by our author in the bipyramidal crystals of sulphate of potash, and under very peculiar circumstances, in several minerals; but we cannot find room for entering at greater length into this subject.

For farther information on the structure of the apophyllite, see the *Edin. Phil. Journ.* vol. i. p. 1; and the *Edin. Trans.* vol. ix. p. 317, where the subject is illustrated with great detail, and with coloured figures.

Sect. XVII.—*On the Multiplication of Images, and their accompanying Colours in Calcareous spar and other Crystals.*

The multiplication of the images in some specimens of calcareous spar was observed by Bartholinus and Huygens, and was afterwards described by Benjamin Martin, Dr. Robison, and Mr. Brougham.

Malus studied these phenomena with particular care; but though his analysis of them is, like all his other investigations, full of ingenuity, yet his explanation, both of the separation of the images, and the colours which accompany them is without foundation.

The crystals of Iceland spar which possess this property, are intersected with one or more planes ABCD, Fig. 10. $e b c g$, $a f h d$, perpendicular to the long diagonals EF, GH, of the rhomboidal faces, and parallel to the edges EG, FH. When we look through the two parallel faces of the crystal at a candle, so that the light may pass through one of these planes, we observe the two principal images A, B, Fig. 11. two secondary images a b, sometimes *four*, viz. a, b; a', b', and sometimes *six*, a, b; a', b'; a'', b''. When there are more than one interrupting plane, the images are often doubled, or multiplied to such a degree that the eye observes, in favourable positions of the rhomboid, heaps of images of the most beautiful kind, sometimes varying in the intensity of their light, sometimes vanishing, and sometimes reappearing. These images are, in general, highly coloured with all the tints of the spectrum; though in some specimens no colours at all appear, excepting the prismatic tinges at their edges, arising from refraction; and by varying the inclination of the rhomboid, the colours which affect the different images change in the most rapid and beautiful manner, running more than once through the whole series of the prismatic colours.

In order to explain these phenomena, Malus supposes *that there is a fissure or crack*, within the crystal, parallel to EG, and perpendicular to EF, Fig. 10. or as shown at AB, Fig. 11. He then supposes a ray R b incident at b. This ray will be divided into two pencils $b l$, $b' l'$, and the ray $b l$ being refracted *ordinarily* at l, will be refracted *ordinarily* at m in the direction $m c$, and *extraordinarily* in the direction $m d'$. In like manner, the ray $b l$, refracted *extraordinarily* at l, will be refracted *ordinarily* at m' into $m' d$, and *extraordinarily* into $m' d'$. The *ordinary* ray $m c$, and the *extraordinary* ray $m' c'$, will be refracted at the surface BF, in parallel directions $c e$, $c' e'$, so as to form the images A, B, in Fig. 12; while the other *ordinary* ray $m' d$, and the *extraordinary* ray $m d'$, will be refracted in the directions $d f$, $d' f'$, so as to form the other two images a b.

With regard to the colours with which the images are tinged, Malus considers them as the colours of a plate of air in the fissure, or crack, and quite similar to the Newtonian colours of thin plates.

By examining with the microscope, and subsequently breaking up the specimens which produce the preceding phenomena, Dr. Brewster found, that in *no case whatever* is there a *fissure or a crack*, in the crystal. He ascertained, however, that the phenomena were produced by veins, or *strata of calcareous spar*, such as ABCD, &c. Fig. 10. always parallel to the long diagonal EF.* He measured the thickness of these veins, which he found to vary from almost imperceptible films to plates of considerable thickness, and he succeeded in determining that these strata were regular rhomboidal plates of the spar, having their axes in a constant position in relation to the axis of the rhomboid which contained them. After these results were established all the phenomena produced by such interrupted crystals admitted of immediate explanation,

Let MN, Fig. 12. be the vein or stratum, of calcareous spar interposed between the two prisms AEB, CFD, and, though it adheres firmly to these prisms by both its surfaces, let us suppose an open interval on each side of it. This stratum intersects the rhomboid so completely, that we can measure with the goniometer the inclination of the projecting rhomboidal face M to the general rhomboidal face GE. Let us now suppose a ray R b incident at b. This ray, after being refracted doubly, will emerge in two pencils at c, c', and will enter the plate of spar MN. As the axis of this stratum is neither parallel nor perpendicular to the plane in which the rays $b c$, $b c'$, are polarised, and as it is so thin as to produce the phenomena of moveable polarisation, each of these pencils will be divided into two complementary tints—suppose *red* and *green*, shown by the double lines $d e$, $d' e'$, in the figure, one of which will retain its primitive polarisation, while the other is polarised in a double azimuth, as in all ordinary cases. These double pencils emerging at e e', and incident upon the second prism CDF at f, f', will be divided, as in the figure, and will emerge at $g h$, $g' h'$, in the directions $g n$, $h m$, $g' n'$, $h' m'$; the two images formed by the rays m, m', being *red*, and the other two images formed by

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* In certain specimens these strata were found in three series, parallel to all the three long diagonals, and in some specimens there were hundreds of them.

n, n', *green*. The various colours, in short, which affect these images, are portions of the single system of coloured rings which surround the axis of the plate MN; and the second prism CDF is precisely an analyzing prism, which separates the tints polarised by the plate MN.

If any doubt could remain of the certainty of this explanation of the phenomena, Dr. Brewster has removed it entirely, by actually composing artificial rhomboids, and interposing a plate of calcareous spar, having the same position as it has in the natural crystal. This artificial rhomboid produced all the various and beautiful phenomena which are displayed in the compound crystal. The phenomena admit of many interesting variations, by substituting one or more thin plates of sulphate of lime, in place of the plate MN of calcareous spar; but we must refer the reader for an account of them, and of various other phenomena observed by Dr. Brewster, and connected with this subject, to the *Phil. Trans.* 1815, p. 270; *Edin. Trans.* vol. viii. p. 165; and the *Transactions of the Geological Society*, vol. v. See also an account of the *Dichroscope* in Part III.

For an account of the experiments of preceding authors, see Bartholinus, *Exper. Cryst. Island.* Exp. XI. p. 17, 18, where the phenomena are ascribed to reflexion from the sides of the crystal; Martin's *Essay on Iceland Crystal*; Brougham's "Further Experiments on Light," *Phil. Trans.* 1797; and Malus, *Théorie de la Double Refraction*, p. 194—198.

SECT. XVIII.—*On the Cause of Double Refraction.*

When Huygens stated that the extraordinary refraction in Iceland spar was explicable on the supposition that the light which composed the extraordinary ray was propagated in spheroidal waves, he furnished us with no information respecting the cause of the phenomena, even if the undulatory theory were demonstrable; and in like manner, when Laplace and Malus assert that the phenomena are explicable by means of a repulsive force emanating from the axis of the rhomb, and varying according to a given law, they gave us no insight into the cause of double refraction. The question still remains,—what produces the spheroidal wave, and what occasions the repulsive force* emanating from the axis of the rhomb?

The discovery of a method of producing the two kinds of double refraction, viz. positive and negative, by compressing and dilating forces, enables us to give an answer to a question which has perplexed the philosophers of the two last centuries.

Let ACBD, Fig. 14 and 15. be two spheres of jelly or glass, and let them both preserve their natural density in the direction AB, which may be called the axis, while a *compressing* force is applied to *increase* the density regularly, as in Fig. 14. from A and B to the equator CD, and a *dilating* force to diminish the density, as in Fig. 15. from A and B to the equator CD. Then it is manifest, that if a ray of light R r is incident perpendicularly at R r, as in Fig. 14. in place of going on unrefracted, as it would do in an uniform medium, it will be attracted towards C, as the density between r and c is greater than the density between r and A. In Fig. 15. on the contrary, the ray R r will be attracted towards A, because the density is greater between r and A than between r and C. The sphere ACBD in Fig. 14. will then represent a *positive* crystal, like *Zircon*, or a circular plate of glass, which has received the *positive* doubly refracting structure by the admission of heat; while the sphere ACBD in Fig. 15. will represent a *negative* crystal, like *calcareous spar*, or a circular plate of glass heated, and in the act of cooling.

Conceiving, therefore, the structure now described as that of the extraordinary medium, the phenomena of the extraordinary refraction is as well explained by this hypothesis as any other fact in physics; and in place of imaginary axes, from which attractive and repulsive forces emanate, a supposition without example in physics, we refer the phenomena of positive and negative crystals to the ordinary attractive forces to which light has always been supposed to be subject. In the *positive* crystals the extraordinary ray is attracted to the *equator*, or *plane of maximum density*, while in the negative crystals it is attracted to the *pole of maximum density*.

In order to explain the co-existence of an ordinary ray along with an extraordinary one, we have only to suppose, that the medium of ordinary refraction accompanies the other medium, and has its density perfectly uniform; so that the portion of the ray R r that enters the ordinary medium will be refracted according to the law of Snellius.

This explanation is equally accordant with the Huygenian theory; for the part of the ray R r that enters the ordinary medium will be propagated in spherical waves, while it is demonstrable that the other part will be propagated in waves of a spheroidal form.

The phenomena of crystals with two axes may be explained on the supposition of the body being spherical, either by conceiving two extraordinary media, which have their compression or dilatation related to two rectangular axes, the degrees of compression being different in each medium; or by conceiving an extraordinary medium with its variations of density related in different degrees to two rectangular axes. Similar effects will be produced, if we suppose the elementary particles of the crystal to be prolate or oblate spheroids, as described by Dr. Brewster in his paper on the laws of polarisation.†

In applying these principles to the explanation of the phenomena of doubly refracting crystals, we must suppose the spheres in Figs. 14. and 15. to represent the particles of which the crystal is composed, as it is only by such a supposition that we can account for the existence of regular axes of double refraction in the minutest fragment of the crystal.

Hitherto we have considered only the division of the ray into two portions, viz. an ordinary and an extraordinary one; but the difficult task remains of explaining the opposite polarisation of the two pencils. If we conceive that a beam of direct light consists of particles in every state of positive and negative polarisation,‡ and that the sides or poles of those which are positively polarised are more liable to be acted upon by the refracting force, while those negatively polarised are more liable to be acted upon by the reflecting force, (a supposition conformable to many facts,) then the positive particles will form the extraordinary ray, while the negative particles are left under the influence of the ordinary force. Hence the two pencils will be polarised in opposite planes, and hence, also, the reason why the extraordinary ray has opposite polarisations in positive and negative crystals.

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* There is no proof whatever of the existence of such a force; on the contrary, the idea of a force residing in an axis, and changing its intensity with the obliquity of the ray to that axis, is an anomaly in physics.

† *Phil. Trans.* 1818, p. 264.

‡ Ibid. 1815, p. 147.

The general views contained in this section, are founded, to a considerable extent, on the phenomena of compressed and dilated solids, and on the condition of circular and rectangular plates of glass that have the polarising structure; and it is a very remarkable circumstance, which justifies us in reasoning from the condition of this kind of glass, to the structure of crystals, that all the tints in the glass may, *mutatis mutandis*, be calculated by the very same formulæ as those of crystallized bodies. See *Edin. Trans.* vol. vii. p. 297; *Phil. Trans.* 1815, p. 60; 1816, p. 136; and 1818, p. 259, Sect. vi.; and 1819, p. 146.

PART II.

ON THE APPLICATION OF OPTICS TO THE EXPLANATION OF NATURAL PHENOMENA.

Having explained, as fully as our limits will permit, the general principles, both of geometrical and physical optics, we shall now proceed to point out their application in the explanation of natural phenomena. As these phenomena are very numerous, we shall attend only to those which are most general and important; such as, 1. The description of the eye and the phenomena of vision; 2. The theory of the rainbow; 3. The theory of halos and parhelia; 4. The phenomena of unusual atmospherical refraction; 5. The colours of the atmosphere; 6. The colours of natural bodies; and 7. The subject of photometry, or the measure of light.

CHAP. I.

On the Eye and Vision.

Sect. I. *Description of the Eye.*

The human eye, which is represented in a vertical section in Fig. 20. and on a still larger scale in Plate XXII. Fig. 8. of Anatomy, consists of four coats and four humours. The outer coat, *a*, *a*, *a*, *a*, is the *sclerotic coat*, or the white part of the eye. It is joined to the cornea, *b*, *b*, or the clear and transparent circular membrane in the front of the eye, which resembles a watch glass, and is of the same thickness throughout. On the interior surface of the sclerotic coat is another membrane, called the *choroid* coat, covered with a black pigment, called the *pigmentum nigrum*, above which lies the retina, a fine reticular membrane, which forms the innermost coat of the eye. The optic nerve enters the eye at O, about $\frac{11}{100}$ths of an inch from the axis of the eye, and towards the nose, and expands itself into the retina. In the very centre of the retina, and the extremity of the axis of the eye, there is a small hole with a yellow margin, called the *foramen centrale*, which is an opening in the retina, and commonly of the form of a cross, having its margin of a brilliant yellow colour.

The interior globe of the eye is divided into two very unequal portions, by a circular plane, EF, called the *iris*, having a circular opening in its centre, called the *pupil*, which expands and contracts according as the light which falls upon it is diminished or increased. The space in front of the *iris*, called the *anterior chamber* of the eye, contains the *aqueous humour*, a fluid which has a refractive power a little greater than water. The space behind the iris, called the *posterior chamber*, contains the *crystalline lens* CD, suspended in a transparent *capsule* by the *ciliary processes* *d*, *d*. This lens has its posterior surface more convex than its anterior one, and consists of concentric coats, composed of fibres, and increasing in density towards its centre.

The following are some of the principal dimensions of the human eye, as given by Dr. Young.

	Hundredth of an Inch.
Length of optical axis . . .	91
Vertical chord of the cornea . . .	45
Versed sine of ditto	11
Horizontal chord of the cornea . .	49
Aperture of the pupil seen through the cornea	27 to 13
Diminished in consequence of the magnifying power of the cornea . .	25 to 12
Radius of the anterior surface of the crystalline lens	30
Radius of the posterior surface . .	22
Distance of the optical centre from the anterior surface of the lens . . .	10
Distance of the optical centre of the lens from the cornea	22
Focal length of the cornea for objects 10 inches distant	115
Joint focus of cornea and lens 91 — 22 =	69
Principal focal distance of lens . .	173
Distance of the centre of the optic nerve from the point opposite to the right .	11
Range of the eye, or field of vision . .	110°

The following measure of the crystalline and cornea were taken by Dr. Brewster and Dr. Gordon, from the eye of a female, above 50 years of age, a few hours after death.

Diameter of the crystalline . .	0.378
Diameter of the cornea . . .	0.400
Thickness of the crystalline . .	0.172
Thickness of the cornea . . .	0.042

The following measures of the refractive powers of the humours of the eye, were taken by Dr. Brewster and Dr. Gordon from the same eye.*

	Index of Refraction.
Refractive power of water . .	1.3358
Ditto of aqueous humour . .	1.3366
Ditto of vitreous humour . .	1.3394
Ditto of outer coat of crystalline .	1.3767
Ditto of middle coat of ditto .	1.3786
Ditto of central part of ditto . .	1.3990
Ditto of the whole crystalline .	1.3839

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* Analogous results were afterwards obtained by Dr. Chossat.

For farther information on this subject, see Petit, *Mem. Acad. Par.* 1728, p. 38. 289; 1729, p. 69; 1730, p. 4. 435; Dr. Young, *Phil Trans.* 1801, and *Nat. Phil.* vol. ii. p. 573; Chossat, *Biblioth. Univers.* 1818, p. 26; and *Edin. Phil. Journal*, vol. i. p. 42.

SECT. II.—*On the Optical Structure of the Crystalline Lens in Man, Fishes, and Quadrupeds.*

It would be foreign to an article on optics to enter into any inquiry respecting the anatomical structure of the lens, which has been examined to a very great extent by Dr. Brewster; but the optical structure of the lens, as developed by the action of polarised light, is too interesting to be passed over unnoticed.

When a recent human crystalline lens is immersed in a trough of glass, containing a fluid of nearly the same refractive power, and when polarised light is transmitted through its axis, it depolarises four faint sectors of light, considerably below the white of the first order, as shown in Fig. 16. thus indicating a positive doubly refracting structure, like a sphere of glass crystallized by rapid cooling, and increasing in density towards the centre.

Upon exposing to a polarised ray the crystalline lens of a large *Cod*, included in its capsule, and plunged in Canada balsam, contained in a hollow parallelopiped of glass, Dr. Brewster observed a regular optical figure, varying its shape during the revolution of the crystalline. He now turned the spherical crystalline, till the diameter which corresponded to the axis of the eye, or the line joining the poles to which the fibres converge, was parallel to the polarised ray, and observed the appearance shown in Fig. 17. consisting of twelve luminous sectors, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, separated from each other by a black cross, and by two dark concentric circles. The interior sectors, 1, 2, 7, 8, were small, and exhibited a white tint of the first order, increasing in brilliancy towards the centre. The middle sectors 3, 4, 9, 10, which are very large, are separated from the interior ones, by a broad dark circle, and display a white tint of the same intensity. The outer sectors 5, 6 11, 12, are extremely faint, and are seen with considerable difficulty in this position of the lens.

By transmitting the polarised light through other two faces of the glass parallelopiped, so as to traverse the crystalline in a line perpendicular to its axis, the optical figure presented new appearances. When the axis of the lens was either parallel or perpendicular to the plane of primitive polarisation, which happened four times in the course of a revolution, it exhibited the form shown in Fig. 18. The tints 1, 2, 7, 8, were now reduced to a pale blue of the first order, and the black cross was very ill defined at the centre. The middle sectors 3, 4. 9, 10, were a little reduced in size, while the exterior ones, 5, 6, 11, 12, had experienced a very sensible augmentation. At intermediate positions of the crystalline, when its axis was inclined 45°, 135°, 225°, and 315,° to the plane of primitive polarisation, the optical figure assumed the appearance shown in Fig. 19. in consequence of the spheroidal form of the lens, where the two sectors 7, 8, are greatly enlarged, and the other two, 1, 2, have wholly, or almost wholly, disappeared.

He now removed the capsule of the lens, so as to let out the semifluid matter which it inclosed, and having rubbed off the very soft exterior coat, he immersed the sphere thus *diminished* in Canada balsam, but he could never observe the exterior sectors, 5, 6, 11, 12; all the other appearances being exhibited as before. He next removed the middle coats of the crystalline, and replacing the nucleus, which was now reduced to one-eighth of an inch in diameter, in the glass parallelopiped, he observed the central sectors, 1, 2, 7, 8, without any of the middle or exterior ones.

If we now take a plate of *sulphate of lime* which polarises a *blue* of the second order, and combine it with the crystalline lens, so that its axis may be parallel to the line 6, 10, 2, 1, 9, 5, the white tints 9, 10, will ascend to a *green* of the second order, while those at 1, 2, 5, 6, will descend to an *orange red* of the first order. In like manner, if the axis of the plate of sulphate of lime is parallel to the line 11, 3, 7, 8, 4, 12, the tints 3, 4, will become green, and 7, 8, 11, 12, an orange red.

Hence it follows, *that the nucleus* 1, 2, 7, 8. *and the exterior coat*, 5, 6, 11, 12, *have the same structure as the negative class of doubly refracting crystals, while the middle coats* 3, 4, 9, 10, *have the structure as in the positive class.*

Dr. Brewster discovered a similar structure in the lenses of many other fishes. In quadrupeds, sometimes *three* structures were seen, and sometimes only two; but in every case, excepting one, the middle, or principal structure, corresponding to 3, 4, and 9, 10, in Fig. 15. was *positive.* For farther information on this subject, see the *Phil. Trans.* 1816, p. 311.

SECT. III.—*On Vision.*

As all the humours of the eye are perfectly transparent, and are bounded by spherical surfaces, the rays of light issuing from any object will experience the same changes by refraction as if they passed through the surfaces of glass lenses; and it is easy, from the propositions and formulæ given in Chap. I. Part I. to trace the progress of a ray of light through the various humours which compose this organ. Let MN, Fig. 20, be an object placed at the distance of a few feet before the eye OEF. Rays of light issuing from the points M, N, and falling upon the cornea *b b*, will be refracted into the aqueous humour between the cornea and the iris, and after being incident on the crystalline lens CD, they will be accurately converged upon the retina, and then form an inverted picture *m n* of the object, in the same manner as if it had been formed by a convex lens. The form of the crystalline, and its increasing density towards the centre, are intended to remove the spherical aberration, by hastening the convergence of the rays that pass near its axis. Hence the image formed on the back part of the eye is more distinct than if it had been formed by any single lens. That an inverted image of objects is formed upon the back part of the eye, may be shown experimentally by cutting away, gradually, with a sharp knife, the sclerotic coat, till it is so thin as to exhibit the image upon the retina.

If all the parts of the eye were permanently fixed, like the lenses in a telescope, it would form a distinct picture only of those objects that were situated at a given distance from the observer. At shorter distances the rays would converge to a point behind the retina, and at greater distances to a point in front of the retina, so that compound images would in both these cases be formed, and vision, of course, rendered indistinct.

That wise Being, however, who has given us this admirable organ, has furnished us also with the means of accommodating it to different distances, although the united wisdom of philosophers and physiologists have not yet discovered the precise method by which it is effected. It is very manifest that the power of adjusting the eye to different distances must be produced either by an alteration in the crystalline lens, by which its convexity is increased and diminished, or by an elongation and contraction of the eye, in virtue of which the retina is removed from, or made to approximate to, the lens, or probably by both these causes acting together. Dr. Young has maintained the first of these opinions with his usual ingenuity; and the experiments of Mr. Ramsden and Sir Everard Home give some countenance to the second. By whatever means, however, this adjustment is effected, its range is very considerable, and its average power seems to be, that of obtaining distant vision at all distances above two inches and nine-tenths. If this power is obtained by increasing the convexity of the cornea, it would be effected by reducing its radius from thirty-one to twenty-five hundredths of an inch, or in the ratio of *five* to *four*. If it is effected by removing the retina from the lens, an elongation of 135 thousandths of an inch, or one-seventh of the diameter of the eye, would be sufficient. If it is effected both by an alteration of the cornea and an elongation of the eye, a reduction of the radius of the cornea one-sixteenth part, or to twenty-nine hundredths of an inch, would be sufficient, provided the eye is at the same time lengthened ninety-seven thousandth parts of an inch, or about one-ninth of its diameter. If it is effected by a change of form in the crystalline, the radius of the anterior surface must be reduced to about twenty-one, and that of the posterior surface to about fifteen, hundredths of an inch.*

When the eye, either from the approach of age, or from any other cause, loses the power of accommodating itself to near objects, the person is said to be *long-sighted*. This imperfection of vision may be remedied by the use of a *convex lens*, which enables the eye to converge to distinct points on the retina the rays which proceed from near objects.

When the eye, on the contrary, from any original conformation or otherwise, has the power only of seeing near objects distinctly, the person is said to be *short-sighted*. This inability of converging the rays from distant objects to points on the retina, is easily remedied by the use of a *concave lens*.

The phenomena of erect vision, by means of an inverted picture, and of single vision, by means of two images on the retina, have long been a source of difficulty among physiologists. If we conceive that the mind views the inverted picture *m n*, Fig. 20. on the retina, in the same manner as an eye behind it would do, the difficulty of accounting for erect vision would be great. Such a hypothesis, however, is certainly without foundation, for we know nothing more than that the mind, residing, as it were, in every point of the retina, refers the impression made upon it at each point to a direction coinciding with the last portion of the ray which conveys the impression. Thus, in Fig. 20. the lower point *m* of the image, formed by rays coming in the direction *m* I, must be referred to the point M, while the rays which form the upper point *n* of the image, coming in the direction *n* I, must be referred to the lower point N of the object MN; and therefore an erect object is the necessary consequence of an inverted image.

The phenomena of single vision from two images admits of an explanation equally satisfactory. Let the rays from the object MN, Fig. 20. fall upon the two eyes X and Z, and form two images *m n*, *m' n'*, on the retina of each. Then, since the point *m* of the image is referred by each eye to the same point M, and the point *n* to the point N, only one object can be seen at MN. If we press the eye X to one side, the image of MN, which it forms, will separate from the image MN formed by the other eye, and the object will appear double. In like manner, if the axes of each eye are directed to a point nearer or farther from the eye than MN, the object will in both cases appear double, as each eye does not refer the same points of the image to the same point in absolute space. When an object, therefore, is seen single with two eyes, it is in reality double, but the two images coincide so accurately, that they appear only as one, and having twice the brightness of the image formed by either eye alone.

The angle which any object MN subtends at the eye, or the angle IMN, is called its *apparent magnitude;* and that angle increases as MN is brought nearer to the eye, and diminishes as MN recedes from it. The point of the finger held near the eye will cover a whole mountain at a distance; and though the real magnitudes of these two objects are very different, yet the apparent magnitude of the finger is greater than that of the mountain. An eye which possesses its full range of adjustment, from about three inches to the greatest distance, has the power of varying the apparent magnitude of objects, or of magnifying them. When an object is placed at the distance of nine inches from the eye, it has a certain angular magnitude; but when it is brought to the distance of three inches, its apparent magnitude is increased three times, or in the ratio of nine to three, and it is, consequently, magnified as many times.

For farther information on the subject of Vision, see the History of Optics, p. 475, also Part i. p. 499; and the article Accidental Colours, vol. i. p. 88. See also Anatomy, vol. i. p. 790, 795; and the article Physiology, chap. xiii. for a full account of the functions of the eye.

CHAP. II.

ON THE RAINBOW.

The phenomena of the rainbow consists, as every person knows, of two bows, or arches, stretching across the sky, and tinged with all the colours of the prismatic spectrum. The internal or principal rainbow, which is often seen without the other, has the *violet* rays *innermost*, and the *red* rays *outermost*, and is part of a circle whose diameter is 82°. The external, or secondary rainbow, which is much fainter than the other, has the violet colour outermost, and the red colour innermost, and has a diameter of about 104°. Sometimes supernumerary bows are seen accompanying the principal bows.

As the rainbow is never seen unless when the sun shines, and when rain is falling, it has been universally ascribed, as we have already seen in the History of Optics, to the decomposition of white light by the refraction of the drops of rain, and their reflexion within the drops. The production of rainbows by the spray of waterfalls, or by drops of water scattered by a brush, or syringe, is an experimental proof of their origin.

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* Dr. Young on the Mechanism of the Eye. *Lect. on Nat. Phil.* vol. ii. p. 585, 586

Let an observer be placed with his back to the sun, and his eye directed through a shower of rain to the part of the sky opposite to the sun. As the drops of rain are spherical particles of water, they will reflect and refract the sun's rays according to the usual laws of refraction and reflexion. A ray of white light $R\,a$, Fig. 21, entering the spherical drop AB at a, will be refracted and dispersed, so that the red ray $a\,b$ will fall upon the back of the drop at b, and the violet ray $a\,c$ at c; from these points they will be reflected again to d and e, and will emerge in the direction $d\,r$, $e\,v$. Now, it is demonstrable that the inclination of the emergent *red* ray $r\,d$ to the incident ray $R\,a$ will be 42° 2′, while the inclination of the *violet* ray $e\,v$ to the ray $R\,a$ will be 40° 17′. Let us now suppose that the ray $R\,a$, Fig. 22. falls on the lower side of a drop of water, and after suffering one refraction at a, suffers *two reflexions* at b, c, and emerges after a second refraction at the points $f\,g$, and in the direction $f\,r$, $g\,v$; then it is demonstrable, that the inclination of the emergent *red* ray $f\,r$ to the ray $R\,a$ will be 50° 59′, and the inclination of the *violet* ray $g\,v$ to $R\,a$, 54° 9′. In both these cases, all the intermediate coloured rays will form intermediate angles between the *red* and the *violet*.

Let us now suppose the observer at O, Fig. 23. looking to a point opposite to the sun, from which the rays R, R, R, &c. proceed, and fall upon the drops H, G, F, E; then, since the position of the rays R, R, is fixed, and also that of the eye at O, the eye can only receive the *red* rays that issue from the drops E, F, (after *two* refractions and one reflexion,) when they are in such a position that the emergent red ray $r\,O$ is inclined 42° 2′ to RF, or (drawing OP parallel to RF, and passing through the eye and the sun) when the angle $r\,OP = R\,r\,o$ is 42° 2′. Hence the eye receiving these red rays, will see them projected against the sky at F. If we now suppose the ray OF, that reaches the eye at O, to turn round the axis OP, so as to describe a conical surface, there will be drops in the prolongation of this surface, from which the ray OF, in all these positions, will be the emergent *red* ray, and, consequently, a *bow of red light* $r'\,r\,r'$ will be seen round the point P, and having a radius FP=42° 2′ or a diameter of 84° 4′; and what is true of any one ray $O\,r$ forming a given angle with OP, the line joining the eye and the sun, must be true of every other ray forming the same angle with OP. By the very same reasoning it may be shown, that a *violet bow* $v'\,v\,v'$ will be formed by the violet rays emerging from the drops at E, and having a radius of 40° 17′, or a diameter of 80° 34′. In like manner, every intermediate coloured ray in the spectrum will give an intermediate bow of its own colour, so that the eye will see a coloured arch consisting of all the prismatic colours, and having its breadth equal to 42° 2′—40° 16′=1° 46′.

The reasoning which we have now applied to those drops, in which there is only one reflexion, may be applied also, *mutatis mutandis*, to those in which there are two reflexions, as in Fig. 21. or as shown at H, G, in Fig. 23. In this case it is demonstrable that the inclination of the emergent *red* ray $f\,r$, Fig. 22. or $r'\,O$, Fig. 23. to OP, will be 50° 58′, and that of the violet bow 54° 10′, giving 3° 12′ for the breadth of the exterior bow, in which all the colours are reversed.

If MN is the horizon, the angle $OQM = NQP$ will be equal to the altitude of the sun; consequently the altitude of any arc $v'\,E\,v'$ of the bow will be equal to the radius of that arc *minus* the sun's altitude, and the radius of any arc will be equal to the altitude of the arc *plus* the sun's altitude. Hence it follows, that when the altitude of the sun is equal to, or exceeds, 42° 2′, the radius of the *red* part of the *primary* bow, no part of the rainbow will be visible; and, in like manner, when the sun's altitude is equal to, or exceeds, 54° 10′, the radius of the *violet* part of the *secondary* bow, no part will be seen. When the sun is in the horizon, the two rainbows will be exact semicircles, but in every other position they will be less than semicircles.

In examining the light of the primary and the secondary rainbow, Dr. Brewster discovered that the light which formed both of them was completely polarised in a plane passing through part of the arch examined and the centre of the bow; that is, in the plane of reflexion within the drops of water; a demonstrative proof, if any were wanting, that the rainbows are formed by reflexion within the drops. Then, if we calculate the polarising angle for one reflexion, at the *second* surface of water, we shall find it to be 36° 51′, which differs only 2° 56′ from 39° 47′, the angle at which the mean rays are actually reflected from the posterior surface of the drops. In like manner, the polarising angle for two reflexions from water, viz. 40° 1′, is within a few degrees of the actual angle at which the light suffers the two reflexions with the drops.

In some particular cases, other coloured bows have been seen within the primary rainbow, and immediately in contact with it. These rainbows, called *supernumerary rainbows*, consist of a succession of bows of red and green light alternately, and gradually diminishing in diameter and in breadth like the coloured rings of thin plates. The first supernumerary red bow is in immediate contact with the violet arch $v'vv'$ of the primary rainbow, and is followed by a green bow, which is again followed by a red bow of less breadth than the first. On the 29th of July, 1813, we had an oportunity of observing these supernumerary rainbows under favourable circumstances, when no fewer than four repetitions of the red and green bows were seen without the primary violet. In the *Philosophical Transactions* for 1723, Dr. Langwith has described in a very distinct manner a bow of this kind; and M. Dicquemarre observed analogous supernumerary bows on the *outside* of the secondary rainbow. Similar phenomena were observed by Monge and Daval. Dr. Thomas Young has explained these phenomena with much ingenuity, by referring them to the interference of different portions of light reflected from the drops of water about one-seventy-sixth of an inch in diameter.

For farther information on the subject of the rainbow, see the History of Optics, Newton's *Optics*, p. 147. 8vo. Smith's *Optics*, vol. i. p. 182; Wood's *Optics*, p. 224; Mariotte. *Mem. Acad. Par.* tom. i. p. 189. Langwith, *Phil. Trans.* 1723, vol. xxxii. p. 241; Pemberton, *Id.* 1723, vol. xxxii. p. 245; Daval, *Id.* 1749, vol. xlvi. p. 193; Dicquemarre, in Rozier's *Journal*, tom. vii. p. 300; Dr. Young, *Phil. Trans.* 1804, or *Lect. on Nat. Phil.* vol. i. p. 470. and vol. ii. p 643; Dr. Brewster's *Treatise* on *New Phil. Instruments*, p. 350,

CHAP. III

ON HALOS, CORONAS, PARHELIA, &C.

Having already, in our article Halo, given a description and representation of the leading phenomena of Halos, with an account of the different theories by which they have been explained, it is unnecessary to resume the subject at present. Several new forms of halos and paraselenæ have been described by Captain Ross and Captain Parry; and Captain Scoresby, in his account of the Arctic Regions, has delineated an immense number of particles of snow, which assume the most beautiful and varied crystallizations all depending more or less on hexahedral combinations of minute particles of ice. When particles of such forms are floating or descending in the air, there can be no difficulty in deriving from them those various and intricate forms which are occasionally met with among this class of phenomena.

It is much to be desired that those navigators who visit Baffin's Bay and the Greenland seas, should examine, by means of a prism of Iceland spar, whether any of the circles or images which compose these luminous meteors consist of polarised light, like the rainbow; for it is very obvious, that if the explanation given of some of the anthelia is correct, the whole, or at least a great portion of the light which forms them, must be polarised. For farther information on this subject, see the works quoted at the end of the article Halo; Captain Ross and Captain Parry's *Voyages;* Captain Scoresby's *Account of the Arctic Regions;* Dr. Young's *Introduction to Medical Literature*, p. 559; and *Edin. Phil. Journ.* vol. v. p. 204.

CHAP. IV.

ON THE UNUSUAL REFRACTION OF THE ATMOSPHERE.

Although the phenomena of unusual refraction have been often observed by astronomers and navigators, yet they do not seem to have attracted particular notice till the year 1797. The unusual elevation of coasts, mountains, and ships, have been long known under the name of *looming;* and the same phenomena, when accompanied with inverted images, have been distinguished in France by the name of the *Mirage*.

In a paper printed in the *Philosophical Transactions* for 1797, Mr. Huddart describes several examples of powerful atmospherical refraction, in consequence of which objects near the horizon appeared inverted, and the horizon itself either elevated or depressed. Mr. Huddart seems to have been the first who described an inverted image beneath the real object; and he accounts for this, and other phenomena of elevation, by supposing that, in consequence of the evaporation of the water, the refractive power of the air is not greatest at the surface of the sea, but at some distance above it, increasing gradually from the surface of the sea to a line which he calls the *line of maximum density*, and thence diminishing gradually upward *ad infinitum*. He then shows, that, in passing through such a medium, the rays of light would move in curve lines, convex upwards when they passed above the line of maximum density, and convex downwards when they passed below the line of maximum density. Hence, two pencils from the object will arrive at the eye, which will produce an inverted image of the object.

In the year 1798, the Rev. Dr. Vince of Cambridge made a series of interesting observations at Ramsgate on the unusual refraction of the atmosphere. He made his observations with a terrestrial telescope magnifying between thirty and forty times, when the height of the eye was about twenty-five feet above the surface of the sea: Sometimes the height of the eye was eighty feet, but no variation in the phenomena seemed to arise from this cause. On the 1st of August, between four and eight o'clock, P. M. he saw the topmasts of a ship as at A, Fig. 1. above the horizon $x\ y$ of the sea: "At the same time, also, he discovered in the field of view, *two* complete images B, C, of the ship *in the air*, vertical to the ship itself, B being *inverted* and C *erect*, having their hulls joined."[*] As the ship receded from the shore, less and less of its masts became visible, and as it *descended* the images B, C, *ascended*; but as the ship did not sink below the horizon, Dr. Vince did not observe at what time and in what order the images vanished.

He then directed his telescope to another ship A, Fig. 2. whose hull was just in the horizon $x\ y$, and he observed a complete inverted image B, the mainmast of which just touched that of the ship itself. In this case there was no second image, as before. While the ship A moved along, B followed its motion, without any change of appearance.

The next ship which Dr. Vince examined, was so far on the other side of the horizon $x\ y$ as just to prevent its hull from being seen, as shown in Fig. 3. Inverted images of some of its parts appeared at x, y, and z; but, what was very remarkable, these images suddenly appeared, and disappeared, "first appearing below, and running up very rapidly, showing more or less of the masts at different times as they broke out, resembling in the swiftness of their breaking out the shooting out of a beam of the aurora borealis." As the ship continued to descend, more of the image gradually appeared, till at last the image of the whole ship was completed, with the mainmasts touching each other. When the ship descended still lower, the image and the ship separated; but no *second* image was observed, as in the first case.

A third ship appeared in the horizon, at a, Fig. 4. the topmast only being seen. An inverted image was seen at B, vertical to a, and an erect image at C, both of them very perfect and well defined, with an image $v\ w$ of the sea between them, the water appearing very distinctly. As the ship approached the horizon the image C gradually disappeared, and during this time the image B descended, but the ships did not run so near to the horizon as to bring the mainmasts together. The two images were visible when the whole ship was actually below the horizon.

On the 17th of August, about $3\frac{1}{2}^{h}$. P. M. Dr. Vince observed a phenomenon like that noticed by Mr. Huddart, as shown in Fig. 5, where A is the real ship, B the image, $e\,r$, $m\,v$ the hulls, $s\,t$ the flag, and $w\,x$ its image just touching it, with the sea $x\;y$ below. The vessel had scarcely come up to the horizon, and as it approached it the image gradually diminished, and totally disappeared when the ship reached the horizon.

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[*] A learned author, in recently giving an account of this fundamental fact, has completely mistaken Dr. Vince's meaning, when he represents the appearances in Fig. 1. as successive, and that at BC as seen when the ship came fuller in view. *All the three ships*, A, B, C, *were seen at once*, and in this consists the beauty of the phenomenon.

In order to account for this phenomena, Dr. Vince "supposes $b\,z$ to be the surface of the sea; $a\,b$ an object, and E the place of the eye; $a\,r$ E, b SE, the progress of two rays by the usual refraction, from the extreme parts of the object to the eye; to these curves draw the tangents E a', E b', and $a'\;b'$ will be the image of the object, as usually formed. Now, if we take the case represented in Fig. 4. let $a''\;b''$ represent the inverted image, and $a'''\;b'''$ the erect image; join a''E, then a'''E, and b''E, b'''E, and these lines must respectively be the directions of the rays entering the eye from a and b, in order to produce the images $a''\;b''$ and $a'''\;b'''$; hence these lines must be tangents at E, to the curves which are described by the rays of light; let, therefore, $a\,n$E, $a\,m$ E, $b\,v$ E, $b\,w$ E, be the curves described. We have therefore to assign a cause, which may bring rays passing above the rays $a\;r$E, bSE, to the eye at E. Now if there were no variation of the refractive power of the air, a ray of light passing through it would describe a straight line; therefore the curvature of a ray of light passing through the atmosphere, depends on the variation of the refractive power of the air. If, therefore, we suppose the air lying above $a\;r$E to vary quicker in its refractive power, than the air through which $a\,r$E passes, the curvature of a ray proceeding above that of $a\,r$E will be greater than the curvature of $a\,r$E; and on this principle we may conceive that a ray may describe the curve $a\;n$E: and, in like manner, if a quicker variation of refractive power should take place above the curve $a\,n$E than in that curve, a third ray may describe the curve $a\;m$E. The same may be said for the rays $b\;v$E, $b\;w$E, diverging from b. The alterations of the refractive power may arise partly from the variations of its density, and partly from the variations of its moisture; and the passage of the rays through the boundary of the fog may there suffer a very considerable refraction; for, from the motion of the fog, and that of the images above-mentioned, Dr. Vince had no doubt that the fog was a very considerable agent in producing the phenomena. When all the causes cooperate, we can easily conceive that they may produce the effects which he has described. If the cause should not operate in the tract of air through which the curves $a\,n$E, $b\,v$ E pass, but should operate in the tract through which $a\;m$E, $b\;w$E pass, an erect image would be visible, but there would be no inverted image; and should it operate in the latter case, but not in the former, there would be only an inverted image."

The subject of unusual atmospherical refraction received much illustration from an ingenious paper of Dr. Wollaston's in the *Phil. Trans.* for 1810. Dr. Wollaston began his inquiry by laying down the following propositions, which we shall give in his own words.

Prop. 1. "*If the density of any medium varies by parallel indefinitely thin strata, any rays of light moving through it in the direction of the strata, will be made to deviate during their passage, and their deviations will be in proportion to the increments of density where they pass.* For each ray will be bent towards the denser strata, by a refracting force proportioned to the difference of the densities above and below the line of its passage; and as their velocities are the same, and therefore the times of action of the forces equal, the deviations will be as the refracting forces, *i. e.* as the increments of density.

Prop. 2. *When two fluids of unusual density are brought into contact and unite by mutual penetration; if the densities at different heights be expressed by ordinates, the curve which terminates these ordinates will have a point of contrary flexure.* For the straight lines $d\;c$ $r\;n$, Fig. 7. which terminate the ordinates $r\;x$, $d\;y$, of uniform density, will be parallel, and, if not united by contrary curvature, some straight line of union, as $a\;o$, must be supposed. But, from whatever cause the first line $a\;o$ is inferred, by the same cause other intermediate lines $m\;p$, $t\;q$, &c. will be produced, and curves $d\;e\;f\;m$, $m\;t\;s\;r$, will be ultimately formed, having a point of contrary flexure at m.

Prop 3. *If parallel rays pass through a medium varying according to the preceding proposition, those above the point of contrary flexure will be made to diverge, and those below the same point will converge, after their passage through it.* For since the deviation of each ray depends on the increment of density where it passes, and since the increment of density is greatest at the point of contrary flexure, any rays, as $a\;b$, Fig. 8. passing near to that point, will be refracted more towards the denser medium than those at $c\;d$, which move in a higher stratum, and will diverge from them, but will be refracted towards and meet those at $e\;f$, which pass nearer to the denser medium, where the increments of density are also less.

Cor. Hence adjacent portions of the converging rays will form a focus, beyond which they will diverge again, and the varied medium will produce effects similar to those caused by a medium of uniform density, having a surface similar to the curve of densities, since convergence or divergence will be produced according as the curve of densities is convex or concave; consequently, by tracing backwards, to the extremities of an object, the progress of the visual rays, or axes of the pencils received by the eye, it will be manifest that any object seen through the inclined concave part $r\;m$, Fig. 9. would appear elevated, erect, and somewhat diminished. An object seen through $m\;d$, where it is convex and inclined, would be elevated; and if situated beyond the focus of visual rays from the eye, it would appear inverted. The magnitude would depend on the relative distances of the eye and the object. Below the point d, where the curve terminates, vision would be direct, so that an object might be situated so as to be seen in all the three ways at the same time, direct at O, inverted at I, and erect again at A."

Considering these propositions as applicable to all cases of varying density, whether they arise from the mutual solution of different fluids, or from a variation of density in the same fluid, Dr. Wollaston made a number of very interesting experiments, which he found to give results perfectly conformable to this theory.

Into a square phial AB, shown in Fig. 10. he poured a small quantity of clear *syrup*, and above this an equal quantity of *water*, which gradually incorporated with the syrup, as seen at A, between the pure water and the pure syrup. The word *syrup*, written on a card, and held behind the bottle, appeared erect through the pure syrup; but when seen through the visible medium of the syrup and water, it appeared inverted thus, *dnɹʎs*, with an erect image above. When the variations of density are great, the object may be held close to the phial; but when they become more gradual, the object is only elongated, and in order to be seen inverted must be held one or two inches behind the phial.

Dr. Wollaston then put nearly the same quantity of *rectified spirit of wine* above the *water*, as in Fig. 10. at B, and he observed the appearance there represented; the true place of the object being in this case seen uppermost, and the inverted and erect images below.

When an oblique line $d\ e\ r$, Fig. 11. is seen through a variable medium, formed as above described, if it is at the distance of the principal focus, one part of it is dilated into a vertical line $l\,m$ (Fig. 11. at A,) if it is beyond that focus, the portion $l\,m$ is inclined backwards, being an inverted image of $d\ l$, and $m\ n$ is another portion of the same image seen erect, (Fig. 11. at B.) By examining a line seen in this way, he found that the appearances continue many hours even with *spirit of wine;* with *syrup*, two or three days; with *sulphuric acid*. four or five; and still longer with a solution of *gum-arabic*.

Dr. Wollaston next heated a poker red hot, and looked along the side of it at a paper ten or twelve feet distant. A perceptible refraction took place at a distance of three-eighths of an inch from it. A letter more than three-eighths of an inch distant, appeared erect as usual; at a less distance there was a faint reversed image of it; and still nearer the poker was a second image erect, as shown in Fig. 12. by the word *Poker* a section of the atmosphere being represented.

The effects of solar heat upon the air adjacent to the surface of a wall, or a painted board, and the effects produced by rapid evaporation, have been detailed by Dr. Wollaston, and will be found in his interesting memoir.

One of the most extraordinary phenomena produced by unusual refraction, was observed by Dr. Vince at Ramsgate on the 6th August, 1806, about 7h. P. M. Between Ramsgate and Dover there is a hill, over which the tops of the four turrets of Dover Castle are usually seen to a person at Ramsgate. At the time above mentioned, however, Dr. Vince, when at Ramsgate, not only saw the four turrets v, x, w, y, but the *whole of the castle* $m\ n\ s\ r$, appearing as if it were situated on the side of the hill next to Ramsgate, and rising as much above the hill AB as usual, *as if it had been brought over and placed on the Ramsgate side af the hill.* This appearance continued about twenty minutes. Between Ramsgate, and the land from which the hill rises, there is about six miles of sea, and from thence to the top of the hill about the same distance, the height of the eye above the surface of the sea being about seventy feet. It is a very singular circumstance in this phenomenon, that the image of the castle was so very strong and well defined that the hill itself did not appear through the image.

In order to explain this phenomenon, Dr. Vince supposes AB, Fig 14, to represent the castle, FC the cliff of Ramsgate, BTD the hill, DC the sea, E the place of the spectator, T the top of the hill, A $y\ v$ E a ray of light coming from the top of the castle to the observer, and B $x\ w$ E another ray coming from the bottom of the castle, and T $x\ z$ E a ray from the summit of the hill, reaching the eye at E, in a direction between those of the other two rays; then it is obvious that such a disposition of the rays will produce the observed appearance. In order to give such a refraction, the density of the air between $y\ v$ E and $x\ w$ E must have varied with great rapidity, so as to increase the curvature of the ray T $x\ z$ E after it cuts B w E in x, so as to make the ray T $x\ z$ E fall between the other two rays.

During the French expedition to Egypt, the phenomena of unusual refraction were often seen. The uniformity of the extensive sandy plains of Lower Egypt is interrupted only by small eminences, on which the villages are situated, in order to escape the inundations of the Nile. In the morning and the evening, as many have remarked, objects appear in their natural form and position; but when the surface of the sandy ground is heated by the sun, the land seems terminated at a certain distance by a general inundation. The villages which are beyond it appear like so many islands situated in the middle of a great lake, and under each village is an inverted image of it. As the observer approaches the limits of the apparent inundation, the imaginary lake which seemed to encircle the village withdraws itself; and the same illusion is reproduced by another village more remote.

Analogous phenomena were observed by MM. Biot and Matthieu over the sandy plains near Dunkirk, and the mathematical theory of these phenomena has been given by the former in the Memoirs of the Institute for 1809. He has shown, that the consecutive trajectories, or paths of the rays, which set out from the eye of the observer, cut one another in their second branches, so as to form a caustic, below which no part can be perceived. This caustic is represented by the curve LT, Fig. 15. and DMS is the limiting trajectory, drawn from the eye of the observer, and touching the ground. It is called the limiting trajectory, because it limits the height where the inversion takes place. All the points in the figure situated above the trajectory can only transmit to the observer a single image, whereas those points in the space SLT transmit two; one erect, and above the object, and the other inverted, and below it. The points, too, situated below the caustic, in the space MLT, transmit no rays, and are invisible, so that a moveable object, such as a man, for example, who is successively removed to different distances, presents the successive appearances shown in Fig. 16. A difference of temperature equal to two centesimal degrees, or 3° 6′ of Fahrenheit, often produced the phenomena of unusual refraction.

In all the preceding cases of unusual refraction, the difference of density in the air has been related to a horizontal line, and consequently the different images have been situated in the same vertical line. A very curious case, however, of a lateral mirage was observed at Geneva, on the 17th Sept. 1818. at 10 o'clock P. M. by MM. Jurine and Soret. A bark near Bellerive, at the distance of about 4000 toises, was seen approaching to Geneva by the *left* bank of the lake, and at the same time an image of the sails was observed above the water, which, instead of following the direction of the bark, separated from it, and appeared to approach Geneva by the *right* bank of the lake, the image moving from *east* to *west*, while the bark moved from *north* to *south*. When the image separated from the bark it was of the same dimensions as the bark, but it diminished as it receded from it, so as to be reduced to one-half when the phenomenon ceased. In this case of unusual refraction the plane of refraction was clearly horizontal; and consequently the two masses of air of different density must have been laterally contiguous to each other.

On the 28th June, 1820, Capt. Scoresby observed some curious examples of unusual refraction, while navigating the Greenland sea, in Lat. 73° 30′, and Long. 11° 50′ W. The sun had shone during the day without the interposition of a cloud, and his rays were peculiarly ardent. About 6 o'clock P. M. a light breeze having sprung up, most of the ships navigating at the distance of ten or fifteen miles, amounting to about eighteen or nineteen sail, began to change their form and magnitude, and, when examined from the mast-head with a telescope, exhibited some extraordinary appearances, different in almost every point of the compass. One ship bearing NW. by W. had an inverted image as at *a*, Fig. 17. above it. Another at *b*, had two distinct inverted images in the air. A third at *d*, bearing about N. was distorted by elongation, the masts being nearly of twice their proper height; and others bearing NNE. and E. and at the distance of twelve or fifteen miles, contracted, as shown at *e* and *f*. These two last ships were beyond the natural horizon, but the ice for a few minutes appeared beyond them. Along with all the images of the ships a reflexion of the ice, in some places in two strata, also appeared in the air, the upper stratum having an altitude of about 15′.

Although the experimental method of illustrating the phenomena of unusual refraction, as given by Dr. Wollaston, is in every respect an excellent one, yet the employment of different fluids does not represent the case which actually exists in nature. The method employed by Dr. Brewster, and which we have already explained in our article on Heat, consists in holding a heated iron GH (see Plate CCLXXXIX. Fig. 8.) above a mass of water, bounded by parallel plates of glass. As the heat descends through the fluid we have a regular variation of density, which gradually increases from the surface to the bottom. If we now withdraw the heated iron, and substitute a cold body in its place, or even allow the air to act alone, the superficial strata of water will give out their heat, so as to have an increase of density from the surface to a certain depth below it. Through the medium thus constituted, all the phenomena of unusual refraction may be seen in the most beautiful manner; the variation of density being produced by heat alone. The same author has produced the same effects with plates of glass, and by applying the heat in different ways to the plate of glass, the remarkable phenomena of Dover Castle may be readily imitated.

For farther information on this subject, see Huddart, *Phil. Trans.* 1797, p. 29. Vince, *Id.* 1799, p. 13; Monge, *Memoires sur l'Egypte*, or in the *Ann. de Chim.* vol. xxix. p. 207; Gruber, Gilbert's *Journal*, vol. iii. p. 377. 439; Woltmann, Gilbert's *Journal*, iii. 397; Wollaston, *Phil. Trans.* 1800, p. 289, 1803, p. 1; Biot, *Mem. de l'Institut*, 1809; MM. Jurine and Soret, in the *Journal de Physique*, March, 1820, tom. xc. p. 217, or in the *Edin. Phil. Journal*, vol. iii. p. 400; Vince, *Edin. Trans.* vol. vi. p. 245; Scoresby, *Edin. Trans.* vol. ix. p. 299; Capt. Colby, *Edin. Phil. Journ.* vol. i. p. 411. See also our articles Fata Morgana, vol. ix. p. 287, and Heat, vol. x. p. 675.

CHAP. V.

ON THE COLOURS OF THE ATMOSPHERE, AND THE COLOURED SHADOWS WHICH THEY PRODUCE.

If the earth's atmosphere consisted of a medium unlimited, and perfectly homogeneous, the sun and the planets would shine in a firmament of the most intense darkness, similar to what has been observed by travellers on the elevated summits of the Alps and the Andes.

As the atmosphere, however, is of limited extent, and composed of strata of variable density, the light of the sun which falls upon it is reflected in every direction, and reaches the surface of the earth with that chaste tinge of blue which forms such a fine relief to the yellowish light of the heavenly bodies.

The blue colour of the sky was attributed by Fromondus, Otto Guericke, Wolfius, and Muschenbroek, to a mixture of light and shadow. Sir Isaac Newton and Bouguer, on the contrary, were of opinion, that the particles of air reflect the blue rays more copiously, and transmit the red, as we have already explained in our article on the Atmosphere.

This explanation, which was then little better than conjecture, has received ample confirmation from the experiments of Dr. Brewster on the polarisation of a great part of the blue light of the sky, from which it follows that it has suffered reflexion. He observed also, that one of the images of certain parts of the sky, formed by a doubly refracting crystal, was much bluer than the other, and that the images changed their tints alternately. Upon the supposition, therefore, that the light of the sky consists of two portions of light, one blue and the other nearly colourless, polarised in different directions, we may explain all the phenomena which appear, when the light of the sky is examined in different azimuths and in different planes passing through the sun.

The phenomena of blue shadows, which have been so often observed, arise from the illumination of the shadows of bodies by the blue light of the sky, the parts without the shadow being illuminated with some other light, such as that of the sun or of a candle. These coloured shadows are generally seen with most distinctness at sun-rise and sun-set, when the sun's light has a yellow tinge.

The colours of shadows illuminated by the sky, vary in different countries, and with different seasons of the year, from pale blue to a violet black; and when there are yellow vapours in the horizon, or yellow light reflected from the lower part of the sky, either at sun-rise or sun-set, the shadows have a strong tinge of green, arising from the mixture of these accidental rays with the blue tint of the shadow.

The phenomena of coloured shadows are often finely seen in the interior of a room. They arise from the blue light of the sky, and the light reflected either from the furniture, or the painted walls of the room. In this case, however, the colours are always complementary to one another.

M. Hassenfratz has written a very elaborate memoir on the subject of coloured shadows, and has deduced the following conclusions from his various experiments and observations:

1*st*, "That the shadows formed by the direct light of the sun and that of the atmosphere vary from *meadow green* to a *violet black*, in a gradation through the *blue*, *indigo*, and *violet*; and that the variation depends on the intensity of the light of the sun compared to that of the atmosphere.

2*d*, That the shadows formed in apartments by the light of the atmosphere and reflected lights, may present all the prismatic colours, more or less changed by black; and that the tints of the shadows observed are always complementary to each other.

3*d*, That the shadows produced on a piece of pasteboard illuminated by artificial lights, are reddish and bluish more or less deep; and that very probably the bluish and reddish tints of the shadows depend on the proportion of hydrogen and carbon in the combustible bodies."

For farther information on the blue light of the sky, and of an instrument for measuring its intensity, see the article CYANOMETER. See also *ActaNova Cæs* tom. ii. App. p. 263; Otto Guericke, *Exp. Magdeburgica*, p. 142, Buffon, *Mem. Acad. Par.* 1743, p. 217; Bouguer, *Traité d' Optique*, p. 368; Smith's *Optics*, vol. ii. Rem. p. 63; Melville, *Edin. Essays*, vol. ii. p. 75; Beguelin, *Mem. Acad. Berlin.* 1767, p. 27; Monge, Rozier's *Journal*, xii. p. 127; Monge, *Ann. de Chim.* tom. iii. p. 131; Rumford, *Phil. Trans.* 1794, p. 107; Hassenfratz, *Journal Polytech.* tom. iv. p. 272, or Nicholson's *Journal*, vi. 281; vii. 23.

CHAP. VI.

ON THE COLOURS OF NATURAL BODIES.

There is no branch of optics more difficult, and more generally interesting, than that which relates to the colours of natural bodies. The splendid tints with which nature has enriched the vegetable, the mineral, and the animal kingdom, have attracted the admiration even of the rudest minds, and have long formed a subject of perplexing research to the natural philosopher.

One of the finest results of Newton's experiments on the colours of thin plates was their application to the explanation of the colours of natural bodies. The whole of the reasoning upon which this explanation is founded, is a striking specimen of the sagacity and address of that extraordinary man, and as his hypothesis has never been clearly explained in our language, we shall think ourselves fortunate if we can convey to the reader a general view of the principles upon which it rests.

1. The surfaces of transparent bodies reflect the greatest quantity of light when their refractive power is the greatest, whether the surface is in contact with air, or separates two media of different refractive powers. When the two media have the same refractive power, there is no reflexion at their separating surfaces, and the quantity of reflected light always increases with the difference of the refractive powers.

This proposition is established by numerous experiments. *Ruby-silver*, *chromate of lead*, *red spar*, *octohedrite*, *diamond*, and the other substances at the head of our table of refractive powers, p. 620, have a much higher lustre, or reflect much more light than any other substance; and *Tabasheer*, *ice*, and *water*, reflect less light than any of the other bodies in the table. If in the manufacture of *glass* we gradually increase the refractive power by adding lead, we at the same time increase its lustre, or its reflective power; and, in like manner, if we add alcohol to water, the lustre of the compound increases with its refractive power.

If we pour *Water* upon a surface of *Crown glass*, the reflective power of the surface will be greatly diminished. If we pour *Alcohol* upon it, it will be diminished still more. *Sulphuric acid* will reduce it still farther; and if we use *Castor oil*, the separating surface will reflect almost no light at all. The analogy between the reflective and the refractive powers of bodies is well shown by the relation between the angle of total reflexion at their second surfaces, and the refractive power; (See p. 619, PROP. III. and p. 652) and it is also indicated in a very striking manner in the polarisation of light by reflexion, which depends on the index of refraction. (See p. 715.)

2. The least parts of almost all natural bodies are in some measure transparent, and the opacity of any body arises from the multitude of reflexions caused in its internal parts.

The transparency of *gold* and *silver*, when reduced into thin films, and of all metallic particles, either when in a state of solution, or when in the form of salts, may be considered as a proof of the proposition. Substances too, that appear perfectly black to the eye, become translucent, and even transparent, when reduced very thin, and exposed to a strong light.

The phenomena of the polarisation of light by metals remove every exception that can be stated to the universality of this truth; for it is demonstrable that part of the light which is reflected by them has actually penetrated the metal; and in plates of steel, polished perfectly flat, we have observed, in the most distinct manner, a variation of density and of refractive power in the infinitely thin transparent film which forms the reflecting surface of the metal.

3. Between the parts of opaque and coloured bodies there are many spaces either empty, or filled with media of different densities, as *water*, for example, between the tinging corpuscles with which any fluid is impregnated; and between the aqueous globules that constitute clouds or mists; and for the most part spaces void of both air and water, but yet perhaps not wholly void of all substance between the parts of hard bodies.

The truth of this proposition is deducible from the two preceding ones; for, by Sect. 2. there are numerous reflexions with bodies, which, by Sect. 1. cannot happen, unless there were interstices between their particles, and of a different refractive power. Besides, many substances, more or less opaque, become transparent by filling their pores with any substance of nearly the same density with their parts; thus *hydrophane* and *tabasheer* become transparent when they have absorbed either oil or water. *Cryolite*, in like manner, has its transparency increased by absorbing water; and *paper*, *vellum*, and various other bodies, become almost transparent by absorption of oil, or other fluids of nearly the same refractive power. On the contrary, all these bodies become opaque when the water or fluid has escaped from their pores. The substance called *Iodine*, which reflects light exactly like metals, is perfectly opaque; but when it is thrown off into vapour by heat, it forms a purple coloured gas, which consists of the solid transparent particles of iodine floating with air between them. When a mixture of turpentine and water, or of water and air, is effected, the compounds become perfectly white and *opaque*, in consequence of the reflexion of light at the particles of turpentine and water, and at the junction of the vesicles of froth with the air which they inclose.

4. The parts of bodies and their interstices must not be less than of some definite bigness, to render them opaque and coloured.

The experiments on thin plates completely prove that, below a certain degree of thickness, the power of bodies to reflect light ceases. Hence, Sir Isaac Newton conceives, that the cause of the transparency of water, glass, &c. is, that they are full of pores, and that their parts and interstices are too small to produce reflexions at their separating surfaces.

5. The transparent parts of bodies, according to their several sizes, reflect rays of one colour, and transmit those of another, for the same reason that thin plates of air and water reflect or transmit those rays.

Sir Isaac Newton conceives, that the *parts* of all natural bodies exhibit the same colours as the bodies, on the same ground that the parts of a film of uniform thickness and colour, have the same colour, as the film, even when slit into threads, or broken into fragments that preserve their thickness. The coloured plumage of birds vary their tints at the same place, by varying the position of the eye, in the same manner as thin plates, and hence the tints arise from the slenderness of the fine hairs which grow out of the feathers. In like manner, the colours of silks, cloths, &c. when penetrated by water or oil, become more faint by immersion in these liquors, and again recover their original colours when they are dry. Leaf gold, some kinds of painted glass, and the infusion of *lignum nephriticum*, reflect one colour and transmit another, like thin plates, and the coloured flowers of plants and vegetables usually become more transparent, or in some degree change their colours by being bruised. The change of colours produced by mixing different fluids is ascribed by Sir Isaac Newton to a change of bulk and of density in the saline particles of the liquor, in consequence of the mutual action. A coloured fluid, for example, may occur transparent, if its particles are by any means divided into smaller ones, and, on the contrary, two transparent fluids may compose a coloured one, by the association of the particles into one cluster.

6. The parts of bodies on which their colours depend are denser than the medium which pervades their interstices.

The colour of a body depends on the rays incident at all obliquities, and as a slight variation of obliquity will alter the reflected tint to various colours, when the particles are rarer than the surrounding medium, to a much greater extent than when the particles are more dense than that medium, and it is probable that the particles are the densest.

7. The size of the component parts of natural bodies may be conjectured from their colours.

A particle, for example, of the same density as *Glass*, which reflects the green of the *third* order, will have its thickness $16\frac{1}{4}$, (See the Table, p. 696, opposite the Green of Third Order, and in the column answering to glass,) or 16 millionths of an inch. In order to determine to what order the colour of any body belongs, Newton has given the following rules.

Scarlet, red, *orange*, and *yellow* colours are most probably of the *second* order, if they are pure and intense. Those of the *first* and *third* order may be good; but the *yellow* of the *first* order is faint, and the *orange* and *red* of the *third* order have a great mixture of violet and blue.

Green colours of the purest kind are of the *third* order, but those of the *fourth* may be good. All vegetable greens seem to be of the *third* order, both from the intensity, and from the circumstances that when they wither, some of them turn to a *greenish yellow*, and others to a more perfect *yellow* or *orange*, or perhaps to *red*, passing first through all the above mentioned intermediate tints. Newton conjectures, that the tinging corpuscles become more dense by the exhalation of the moisture, and may be also augmented in size by the accretion of the oily and earthy part of that moisture: As the changes which the green leaves of plants, as well as their coloured petals undergo, are gradual, the colours into which they pass will be of the same order.

Blue and purple colours, when the brightest, are of the *third* order, but they may also be of the *second*. Newton considers the above true of *violets*, or of the second order, "because their syrup by acid liquor turns *red*, and by ærinous and alcalizate turns *green*," and if there should be any body of a deeper and less reddish purple than that of violets, he would consider it as of the *second* order.

The faint pale *blue* of the first order he supposes to be the azure colour of the purest and most transparent sky, formed by particles of vapour before they have arrived at the size requisite to reflect other colours.

Whiteness, when it is most luminous and intense, is that of the first order, such as that of *white metals;* but when it is less strong and luminous, it is a mixture of all the colours, such as the whiteness of *froth*, *linen*, *paper*, &c. and the greater number of white substances. The colours of *gold* and *copper* are probably of the second or third order.

Blackness is produced when the particles of the body are less than any of those which produce colours. The effect of a change of condition in the particles of a coloured body in producing blackness is finely exemplified in an interesting experiment on *phosphorus*, which was made by M. Thenard. Having obtained some very pure phosphorus of the usual *yellow* colour, after repeated distillation, he found that it possessed the singular property of becoming *perfectly black*, when it was melted and suddenly cooled. If it was again melted when in its black state, it recovered its yellow colour, and could thus be made either *black* or *yellow*, at pleasure.

Newton looked forward to the improvement of the microscope as the means of actually discovering the particles of bodies upon which their colours depend; and he conjectures that, excepting those which produce blackness, they might be all discerned by a microscope which magnified *three* or *four thousand* times.

Before we conclude this section, we shall mention some curious facts, which both illustrate and support the Newtonian theory of the colours of natural bodies.

1. Dr. Drummond of Belfast observed, that the membrane behind the retina of the dog, and other animals, which produce those *blue*, or *green*, or sometimes *red* reflexions, which often shine with such brilliancy in the living animal, loses the power of reflecting these tints when it is dry, and becomes entirely black. Upon learning this fact from Dr. Drummond, we prepared several eyes that reflected these colours with great vivacity, and invariably found that they became black when dry, and blue and green when softened with water. After some of them had remained *four or five years in a dry state*, they still possessed the property of developing their colours by moisture. It is worthy of remark, however, that the *black* passed instantly into a brilliant *blue*, the *blue* into *green*, and the *green* into a *greenish yellow*.

2. Tincture of *turnsole*, when it has long been shut up in a bottle, well corked, often becomes of an *orange* colour, an effect which is supposed to arise from deoxidation. If the bottle is opened, and the fluid agitated

so as to make it combine with the oxygen of the air, it becomes *red* in a few minutes, and then violet blue.

3. When pure and solid oxide of manganese, which is of a brown colour, is heated with potash, there arises a solid combination, whose colour is a lively green, apparently of the third order. When this combination, which is called the *cameleon mineral*, is dissolved in a great quantity of warm water, it is rapidly disunited, and the oxide separated from it. But if the combination has been well prepared, and if a small quantity of water is employed, the separation of its parts takes place gradually, and the solution assumes a variety of colours in succession. From *green* it passes to *bluish-green*, then to *blue*, next to *purple*, and lastly to a *reddish purple*, the tints gradually descending in the order of the rings.

4. If oil of sweet almonds is mixed with soap and sulphuric acid, the combination will at first be *yellow*, and successively *orange-yellow*, *deep orange*, *red*, and *violet*, which is the series of colours in passing from the first to the second order. During the transition from the *orange* to the *red*, there is a time when the absorption of the incident rays becomes so strong, that the mixture appears almost black. The same interruption is observed when we substitute for the almond oil the oil which is obtained from alcohol, treated with chlorine. In this case, the succession of colours is a *pale yellow* of the first order, *orange*, *black*, *red*, *violet*, and lastly a fine *blue* of the second order. The flower of the *cobea* exhibits a similar phenomenon. When it first opens, it is of an imperfect yellowish-green colour, which is evidently that of the second order, but it is soon covered with spots of violet, and in a few hours becomes entirely violet, without passing through the intermediate blue. When the flower withers, however, it passes from the violet to the blue.

5. The substance called *hematine*, discovered by M. Chevreul, is of a greyish tint when it is pure and solid. When dissolved in water, to which some atoms of acetic acid have been added, its colour is of a *yellow* of the second order *slightly green*. If the fluid in this state is introduced under a tube filled with mercury, and is then heated by surrounding it with a hot iron, it becomes successively *yellow*, brilliant *orange*, brilliant *red*, *purple*, and bluish *purple*. When kept by itself to cool, it returns gradually to its first colour, which it requires some days to do if the quantity employed is about half of a centilitre.[*]

Effects somewhat analogous to those which have been described, are exhibited in the changes which heat produces on the colouring matter of minerals. In subjecting the *Balas Ruby* to high degrees of heat, Dr. Brewster observed that the ruby became green, which gradually faded into a *brown* as the cooling advanced, which rose by degrees to its original brilliant *red* colour. M. Berzelius observed an analogous fact in the *Spinelle* of Ceylon and Aker, which becomes *brown* by heat, then blackens, and becomes opaque as the heat increases. It then passes through a fine chrome *green* before it recovers its *red* colour.

See Newton's *Optics*, book ii. part iii. p. 217; Delaval, in *Manchester Memoirs*, vol. ii. p. 131; Biot's *Traité de Physique*, tom. iv. p. 123; *Edinburgh Philosophical Journal*, vol. vi. p. 379; vol. vii. p. 180; Berzelius, *De L'Emploi de Chalumeau*, p. 289, 252.

CHAP. VII.

ON PHOTOMETRY, OR THE MEASURE OF LIGHT.

The most valuable experiments which have hitherto been made on the subject of photometry, we owe to the genius of Bouguer and Lambert, of whose labours we have already given a general account in the history of the science.

In order to measure the quantity of light lost by reflexion, Bouguer placed the reflecting surface to be tried at B, Fig. 18. and by means of a lamp or candle at P, he illuminated two tablets D, E, parallel to one another, and having precisely the same degree of whiteness. He then placed his eye at A, so that he could see at the same time the tablet E *directly*, and the image of the tablet D reflected from the mirror B. When the direct and reflected images were brought into contact, so that the eye could compare together their degrees of illumination, he caused the candle to be moved along the line ED, so as to throw more or less light upon either of them till the intensity of their light appeared perfectly equal. The square of the distances EP and DP afforded an expression of the diminution of the light by reflexion. By this, and various other methods adapted to the nature of the case, he obtained the results given in the following Table.

Light reflected from Water *at different angles of incidence, according to Bouguer.*

Angles of Incidence.	No. of rays reflected out of 1000.	Angles of Incidence.	No. of rays reflected out of 1000.	Angles of Incidence.	No. of rays reflected out of 1000.
89½°	721	80°	333	50°	34
89	692	77½	271	40	22
88½	669	75	211	30	19
88	639	72½	178	20	18
87½	614	70	145	10	18
85	501	65	97	0	18
82½	409	60	65		

By comparing these results with the quantity of light reflected from quicksilver, Bouguer concluded that, at great angles of incidence, water reflected as much light as quicksilver. The following measures for quicksilver are deduced from Bouguer's comparison of its reflective force with that of water.

Angles of Incidence.	Rays reflected out of 1000.
89½	721
40	704
0	666

M. Bouguer obtained the following results from a plate of looking-glass not quicksilvered.

Light reflected from Plate Glass *at different angles of incidence.*

Angles of Incidence.	No. of rays reflected out of 1000.	Angles of Incidence.	No. of rays reflected out of 1000.	Angles of Incidence.	No. of rays reflected out of 1000.
87½°	584	64°	149	50°	57
85	543	60	112	44	40
82½	474	59	105	40	34
80	412	56	85	35	29
77½	356	55	79	30	27
75	299	54	74	20	25
70	222	53	69	10	25
69	210	52	65	0	25
65	156	51	61		

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[*] See a fuller account of these last four facts in Biot's *Traité de Physique*, tom. iv. p. 134.

The following Table contains Bouguer's experiments on the reflexion of light from white opaque bodies.

Light reflected from white opaque bodies *at different angles of incidence.*

Angles of Incidence.	No. of Rays Reflected out of 1000. Silver.	Plaster.	Dutch Paper.
0	1000	1000	1000
15	802	762	971
13	640	640	743
45	455	529	507
60	319	352	332
75	209	194	205

In his very interesting work on Photometry, Lambert has investigated at great length the reflexion of light from one or more plates of glass at various angles of incidence. As the methods which he employed are remarkable for their ingenuity, we shall endeavour to make them intelligible to the reader before we detail the results to which he was conducted.

Let ABCD be a plane white surface, on which is drawn a line ILK, which is every where of equal blackness. A plate of glass, EFGH, was placed at right angles to the white surface, so that the angle HLK was a few degrees less than a right angle. When the plane ABCD was equally illuminated by the sun, or by a candle, or by the light of the sky, the observer placed at O viewed the posterior part IL of the line IK projected into LQ, and the anterior part of it KL reflected at LP. Both of these images had an ash-grey colour, which varied in intensity as the position of the eye was changed; for with the image of IL was mixed the reflected image of the plane white ground LN; and, on the contrary, the reflected image LP was mixed with the image of part of the plane at LM, seen by refraction. The candle being removed to such a distance, that the rays were nearly parallel, Lambert sought the position of the eye at O, where the two lines LQ, LP, appeared of equal paleness, which was very easy, as the light of the one increased, while that of the other diminished. When this position was determined, he measured the angle of incidence, and found it 75½°. Hence it follows, on the supposition that the glass is perfectly pellucid, *that at an angle of 75½°, the quantity of light reflected is exactly equal to the quantity of transmitted light, whatever be the intensity of the incident rays.*

Various plates of glass, from 1 to 9, were now substituted in the place of EFGH; and in the same way Lambert determined the different angles, at which the light reflected from the plates was equal to the light transmitted. Thus

No. of Plates of Glass.	Angles of Incidence at which the reflected and transmitted Light is equal.	No. of Plates of Glass.	Angles of Incidence at which the reflected and transmitted Light is equal.
1	75½	6	51
2	68	7	47
3	63	8	43
4	59	9	39½
5	55		

If we now call M the quantity of *reflected*, and N the quantity of *transmitted* light, it is necessary to determine their relative values at different angles of incidence.

In order to do this, Lambert made the light fall upon a sheet of white paper, FD, Fig. 20. A plate of glass AB was then inclined, so that the light reflected in the direction CE, and refracted in CD, illuminated equally the spaces EA, AD. In this case it is demonstrable, that the reflected is to the refracted light, or M : N = AE : AD. In this way he obtained the following results:

Angles of Incidence.	Light Reflected, or M.	Light Refracted, or N.	Ratio of M : N.
75½	½	½	1 : 1
68	⅓	⅔	1 : 2
63	¼	¾	1 : 3
59	⅕	⅘	1 : 4
55	⅙	⅚	1 : 5
51	1/7	6/7	1 : 6
47	⅛	⅞	1 : 7
43	1/9	8/9	1 : 9
39½	1/10	9/10	1 : 10

As the value of M consists of two portions, viz. q, the quantity of light reflected at the first surface, and p, the quantity reflected by the second surface of the glass, it became necessary to determine by experiment the ratio of these two quantities. For this purpose he placed a plate of glass AB, Fig. 21. so that it might reflect by both its surfaces, the incident light coming in the direction LE, upon the white paper DA; and he inclined a glass prism AC, so as to reflect by its anterior surface light coming in the same direction LF, and he observed the angles of incidence on the plate and the prism, when they illuminated the space AH equally. The following are the results of two experiments

	Experiment I.	Experiment II.
AE	1	1
AH	0.90	2.10
AG	0.67	1.02
Angle CAE . . .	15°	19°
LEB	42	65
Corresponding angle of incidence	48	25
LFG	27	46
Corresponding angle of incidence	63	44

Now, the illumination of the space AG$=\frac{q}{\text{AG}}$, and of AH$=\frac{\text{M}}{\text{AH}}$, which being equal by the experiment, we have $\frac{q}{\text{AG}}=\frac{\text{M}}{\text{AH}}$, and $q=\frac{\text{M}\times\text{AG}}{\text{AH}}$.

5

But since, by the preceding Table, M $=\frac{1}{7}$, when the angle of incidence is $=51°$; or LEB$=39°$. and M$=\frac{1}{8}$, when the angle of incidence is $=47°$, or LEB$=43°$: then, by taking proportional parts, we shall have M$=\frac{1}{8}\div\frac{1}{224}=0.12054$ for an angle of incidence of 48°; consequently $q=\frac{67\ \text{M}}{90}=0.08972$, which is the quantity of light reflected from the *exterior*, or *first* surface of the prism, at an angle of incidence of 63°.

In the same experiment, the angle LFC$=27°$, and the angle of incidence 63°, and for this angle M$=\frac{1}{4}$. But as Lambert has shown that M$=\frac{q+p}{1+p}$, and $p=\frac{\text{M}-q}{1-\text{M}}$, we have $p=0\ 21370$, which is the quantity of light reflected from the *internal* or *second* surface of the glass plate.

In the second experiment, where HEL = 65°, or angle of incidence = 25°, we shall, in like manner, have $q = 0.03736$, and $p = 0\,08297$.

Lambert now arranged the experiment as in Fig. 22. where both the prism and the plate of glass are inclined to the paper DA, and when AG and AH were equally illuminated, he took the following measures:

AE = 1 Angle BAD = 57° LFC = 13½°
AG = 0.47 LEB = 25° Angle of incid. 76½°
AH = 0.42 Angle of incid. 65° FAC = 11½°

By taking proportional parts, M will be = 0.28333 for 65°; hence $q = \frac{M \times AG}{AH} = 0.31706$, which is the quantity of light from the prism, corresponding to an angle of incidence of 76½°. In like manner we shall have $p = 0\,58696$.

From the above experiments Lambert deduced the following Table.

Angle of Incidence from the Perpendicular.	*Calculated.*			*Observed.*	Differences between the Observed and Calculated Results.
	Light Reflected at the first Surface = q.	Light Reflected from the second Surface = p.	Quantity of Reflected Light = M.	Quantity of Reflected Light = M.	
75½°	0.2741	0.5136	0.5205	0.5000	+ 0.0205
68	0.1333	0.2753	0.3204	0.3333	— 0.0130
63	0.0928	0.1968	0.2421	0.2500	— 0.0079
59	0.0729	0.1566	0.1985	0.2000	— 0.0015
55	0.0592	0.1283	0.1663	0.1667	— 0.0004
51	0.0494	0.1078	0.1428	0.1429	— 0.0001
47	0.0423	0.0925	0.1234	0.1250	— 0.0016
43	0.0368	0.0810	0.1091	0.1111	— 0.0020
40½	0.0332	0.0731	1.0991	0.1000	— 0.009

From this Table Lambert deduced the following for every tenth degree.

Angle of Incidence.	q	p	M	N
80°	0.4862	0.7766	0.7108	0.2892
70	0.1578	0 3204	0.3622	0.6378
60	0.0772	0.1653	0.2070	0.7930
50	0.0474	0.1046	0.1376	0 8624
40	0.0337	0.0705	0.0973	0.9027
30	0.0264	0 0585	0.0802	0.9198
20	0.0225	0.0499	0.0690	0.9310
10	0.0203	0.0450	0.0624	0.9376
0	0.0199	0 0448	0 0619	0.9381

From these data we may deduce the light reflected or transmitted by any number of transparent glasses, by means of the following formulæ, given by Lambert, where x is the number of glass plates, X the reflected light, and Y the transmitted light.

$$X = \frac{x\,M}{1 + (x - 1)\,M}\quad Y = \frac{N}{1 - (x - 1)\,M}.$$

Thus, for a right angle, when M = 0.0619, we have $X = \frac{x}{15.1535 + x} = 1 - Y$; consequently we obtain the following results.

Number of Glass Plates.	Light Reflected, or X.	Light Transmitted, or Y.
1	0.0619	0.9381
2	0.1166	0.8834
3	0.1652	0.8348
4	0.2088	0.7912
5	0.2481	0.7519
6	0.2836	0.7164
7	0 3158	0.6842
8	0.3455	0.6545

By using plates of glass that were less pellucid, Lambert obtained the results in the following Table.

Number of Glass Plates.	Light Reflected.	Light Transmitted.	Light Lost.
1	0.0516	0.8111	0.1373
2	0.0856	0.6596	0.2548
3	0.1081	0 5368	0.3551
4	0.1228	0.4377	0.4495
8	0.1467	0.1945	0 6588
16	0.1524	0.0387	0.8089
32	0.1526	0.0016	0.8458

Since the time of Lambert only a few experiments have been made in photometry Count Rumford found, that when light was transmitted perpendicularly through a thin, clear, and colourless pane of window glass, the loss was only .1263; that is, out of 10,000 rays, 8737 rays were transmitted. When a pane of fine, clear, and well polished glass, such as that commonly used for looking-glasses, was used, the loss of light was .1973, or the rays out of 10,000 that were transmitted were 8027. When two such plates were used, so as to stand parallel, but not to touch each other, the loss was 3184 of the whole, or the light transmitted was 6816. These results differ very considerably from those of Lambert and Bouguer, and make the loss of light much greater than it seems to be. Dr. Herschel found, that the light transmitted by one eye-glass was 9482, by two eye-glasses .89918, and by three eye-glasses 85265.

In examining the reflecting power of glass mirrors, Lambert found, that the light reflected at a perpendicular incidence was 5352 out of 10,000 rays, the quantity lost being 4648. In separating, however, the light reflected from the first surface of the glass, he found that, in general, the quicksilvered surface may be considered as reflecting two-thirds of the light which falls upon it. When the inclination of the incident rays to the perpendicular is about 30°, Lambert considers that the glass mirror reflects about two-thirds of the incident rays. It is much to be regretted, that no person has yet undertaken a series of experiments on the reflective power of the different metals, and on the variation of intensity in the reflected rays, produced by varying the angle of incidence. The results obtained by Bouguer for quicksilver, and given in p. 758, are computed from the comparative effects which he has given of the reflecting power of quicksilver and water. One of his experiments, which we have not inserted, gives the very anomalous result of a maximum of reflective power at a considerable angle of incidence, which Bouguer does not seem to have observed. If this shall turn out to be the case, it will connect itself, in a very interesting manner, with the angle of maximum polarisation in metals. In order to determine the penetrating power of his reflecting telescopes, Dr. Herschel made some experiments on the reflective power of metals, of which the specula were composed, and he found that a perfectly polished surface of this metal reflected 67,162 out of 100,000 rays, at a vertical incidence; which is a result very near that which Bouguer found for quicksilver. After two reflexions, the light reflected amounted only to 45,242 of the first 100,000 rays. We would recommend the prosecution of this interesting branch of optics to the attention of some of our young and active philosophers.

For farther information on this subject, see Bouguer's *Traité de Optique*; Lambert's *Photometria*, p. 184. 209. 227, &c.; Rumford, *Phil. Trans.* 1794, p. 67.; and Herschel, *Phil. Trans.* 1800, p. 49.

PART III.

ON OPTICAL INSTRUMENTS, AND THE METHOD OF CONSTRUCTING THEM.

Although we have already had occasion, under several heads, to describe the construction and use of a few individual optical instruments, yet the general principles of their construction have, in most cases, been reserved for the present article. In the following chapters, therefore, we shall resume the consideration of some of those that have been previously described, without repeating any of the particular details that have already been given.

CHAP. I.

DESCRIPTION OF OPTICAL INSTRUMENTS.

Sect. I.—*The Multiplying Glass.*

The multiplying glass is an instrument by which an object is multiplied any number of times without being magnified.

The common multiplying glass, shown in Fig. 23. is made by grinding a number of flat planes upon the convex side $h\,i\,k$ of a plano-convex lens AB, such as $h\,b$, $b\,l\,d$, and $d\,k$. When an object C is placed at a distance exceeding six inches, or that of distinct vision, as many images of it will be seen by an eye placed at H as there are flat faces cut upon the lens. A distinct and colourless image will obviously be seen at C, through the two flat surfaces $b\,d$, $e\,f$; but as every other face is inclined to the plane surface $b\,k$, these inclined faces will constitute so many prisms, by which the light will be refracted, as described in page 633. By means of the prism $h\,b\,e$, for example, a ray of light $a\,b$, proceeding from C, will be refracted in the direction $b\,e$ H, and reaching the eye in the direction e H, the image of C will appear at E. In like manner, by means of the prism $d\,f\,k$, another image of C will appear at D. There will, therefore, be a circle of images arranged round C as a centre, and containing as many as there are faces round the vertical one $b\,d$. If a second circle of flat planes were cut without the first circle, so as to produce another set of prisms with greater refracting angles, a second circle of images would be seen round C. All these images, however, will be highly coloured by refraction except that at C. In order to see the images to advantage, the eye must be situated at H, the point of concourse of the refracted rays.

The multiplying glass may be rendered achromatic, by placing a flat plate of glass $m\,n$ upon the central face $b\,d$, and introducing a fluid between it and the cut surface of the glass. If this fluid has a less refractive and a greater dispersive power than the glass, all the prismatic colours will be corrected, and a considerable balance of refractive power left to produce the multiplication, or to separate the images D and E from C.

There are many transparent minerals which are crossed with veins or strata of the same substance, which, though bounded by parallel faces, possess the property of multiplying glasses in the highest perfection. In Sect. XVII. p. 746. we have already had occasion to treat of this class of phenomena. In some specimens of Iceland spar, intersected with more than one series of veins, and found near Montrose, the property of multiplication is such, that almost 100 images may be seen heaped up in pyramids. In describing an instrument called a *Dichroscope*, we shall have occasion to resume this subject.

Sect. II.—*On the common Looking Glass.*

We have already explained (see p. 657.) the principles upon which every plane mirror CD, Fig. 24. forms an image EF, of the same size and form as the object AB, and at the same distance behind it. If the length of the mirror CD is *only half* the length of the human figure AB, then the eye of the figure at A will see *the whole* of his figure at EF. The image of the head at E will be seen in the direction AE, by the rays AC, incident perpendicularly on the mirror at C, and reflected back to the eye at A, and the image of the part at F will be seen by rays BD incident at D, and reflected to the eye at A, in the direction AD; so that if a D is a perpendicular at D, $a\,\mathrm{DA}=a\,\mathrm{DB}$. Hence $\mathrm{A}\,a=a\,\mathrm{B}=\frac{1}{2}\,\mathrm{AB}$; and on account of the parallelism of AC, CD, we have $\mathrm{CD}=\mathrm{A}\,a=\frac{1}{2}\,\mathrm{AB}$.

If the looking glass is brought nearer to the observer, and is placed at $c\,d$, the effect will still be the same. The person AB will see his image at CG, and we shall have $c\,d=\frac{1}{2}\,\mathrm{AB}$, as before.

In all plane mirrors, particularly when they consist of a single reflecting surface, the brightness of the image of the observer's eye will always be a *minimum*, and the brightness of other parts of his body will increase, the more remote they are from the eye. The eye being always seen by rays incident perpendicularly, there will be a greater number of them lost by reflexion, as the image of the parts most distant from the eye is necessarily formed by rays that have been reflected at the greatest angle. This difference in the intensity of the light, and different parts of the observer's image, increases as he approaches to the mirror; for when the mirror is brought to $e\,d$, the image of his feet is seen by rays B d, reflected at an angle A d a, nearly twice as great as the former angle AD a; hence the image of his feet will be much brighter than before.

Another peculiarity in the plane mirror, is the reversion of the image; the *right* hand opposing the *left*, and the *left* hand the *right*; and hence it is used by artists for reversing drawings. The word NEWTON, for example, in front of the mirror CD, will be reversed, as in Fig. 24. See the article KALEIDOSCOPE.

SECT. III.—*On Pyramidal Glasses for combining the separated parts of an Image.*

These pyramidal glasses, one of which is represented in Fig. 1. consists of a number of flat faces, ground upon the surface of a cone of glass, so as to form a pyramid with a flat and highly polished base. They consist, therefore, of as many prisms as the pyramid has sides; so that if the eye is placed above the vertex A, it will receive a portion of the rays refracted by each prism, and consequently coming from remote points, M, N, O, P, and will see these points collected together, or combined immediately below the axis of the pyramid. Let us suppose that the pyramid has four faces, fronting north, south, east, and west, and that the picture of a bird is divided into four parts, the head being at M, the tail at N, and the two wings at O and P, then we can conceive these parts placed in such a manner that their images, after refraction through the four prisms, shall all be combined together below the glass pyramid, and form a complete bird.

In order to render the deception more complete, the four parts of the bird are connected together with fanciful figures, which are *not visible* through the pyramid, so that the picture above which the pyramidal glass is set appears to be a mass of inextricable confusion. We have seen some of these glasses containing twelve faces, so that the picture, whose scattered parts it combines, must be divided into twelve portions. When well made, this instrument is a very amusing one, and never fails to surprise and perplex the person who sees it for the first time.

SECT. IV.—*On Pyramidal Reflectors, for combining the separated Parts of Objects.*

Notwithstanding the agreeableness of the effect produced by the preceding instrument, yet the refracting angle of the prism is so great, as to render the image extremely indistinct by the quantity of prismatic colours with which its parts are affected. A contrivance, indeed, might be adopted for rendering it achromatic, but this would render it too complicated an instrument for ordinary use, especially as the same effect may be produced by reflexion. It is evident, that if the incident rays from M, N, O, P, Fig. 1. and the refracted rays which enter the eye above A, became the incident rays and the reflected rays from a series of mirrors or reflectors arranged symmetrically round the axis AQ, the very same effect will be produced as by the pyramidal glasses. For this purpose, a pyramid made of steel, or speculum metal, should have a series of plane surfaces, cut and polished so as to meet at the summit A, and form equal angles with the axis AQ; and the pyramid may be made a double one, by uniting another of a different altitude, and of a different number of sides, to its base BC, so as to suit a different set of pictures when inverted. When the parts of a picture are arranged symmetrically round the base BC, at the distance of distinct vision, and so that rays coming from each of them may rise in the planes of reflexion from each of the reflecting faces passing through A, they will all be seen to an eye above A, inverted in the same manner as with the pyramidal glass, but perfectly free of distortion and colour.

The same effect may be produced, and in a still better manner, by a pyramid composed of a series of prisms, the separated images being reflected to the eye by the total reflexion from the posterior surfaces of each prism. A section of two of the prisms is shown at *a b c*, *a d e*, Fig. 2. in which *a e*, *a c*, are the reflecting surfaces, and the angles at *a e* and *c* equal, and of such a size that the light suffers total reflexion from *a e*, and *a c*.

SECT. V.—*On Cylindrical Mirrors.*

If the surface of a metallic cylinder is highly polished, and the cylinder is set upon its base, near a picture lying horizontally, the image of the picture seen by reflexion from the polished surface, is distorted in the most irregular manner, in consequence of the surface of the mirror being plane in a section passing through its axis, circular in a section perpendicular to this, and of a different curvature in all intermediate sections. On the contrary, we may conceive a picture distorted according to given laws, which, when seen by reflexion in the cylindrical mirror, shall appear of the most just and harmonious proportions. This, accordingly, is the purpose for which cylindrical mirrors are used. They are generally accompanied with a set of distorted figures, which have neither shape nor meaning when seen by themselves; but when they are placed in a particular position before a cylindrical mirror, their image is at once reduced into form and expression. The effect of a cylindrical mirror is shown in Fig. 3. The method of drawing a figure, which will be restored to its proper form by reflexion from a cylindrical surface, has already been explained under our article ANAMORPHOSIS.

SECT. VI.—*On Spectacles and Reading Glasses.*

The theory of spectacles and glasses for aiding imperfect vision, has already been given in a preceding section. (See p. 749.) When a glass is intended merely for a reading glass, or for obtaining distinct vision of objects placed within a foot or two of the eye, the lens must be convex for all eyes, and the focal length must depend entirely on the degree of magnifying power which is required; for when the object is placed in the anterior focus of a convex lens, whether it is very small, like that of a single microscope, or large, like that of a reading glass, both a short and a long-sighted person will have distinct vision, the difference in the condition of their eyes being compensated by the slightest difference in the distance of the object from the glass.

When it is required, however, to enable the eye of a short-sighted or a long-sighted person to see objects distinctly at a greater distance, a lens must be selected by the following rules.

If the person is short-sighted, multiply the distance at which he sees minute objects most distinctly, by the distance at which he wishes to see most distinctly by the use of a concave glass, and divide this product by the difference of the above distance. The quotient will be the focal length of the concave lens required. If the distance at which it is required to see distinctly be very great, that is, beyond 200 or 300 yards, then the focal length of the concave glass will be nearly equal to the distance at which the person sees distinctly.

When the person is long-sighted, and cannot see near objects, but has a distinct vision of remote ones, then the focal distance of the convex lens is found by the very same rule; but if the distance at which he sees most distinctly is very great, then the focal length of the convex lens will be equal to the distance at which he wishes to see objects most distinctly

The proper selection of glasses for imperfect vision is a point of much deeper importance than is generally believed. An oculist who is acquainted only with the diseases of the human eye, without possessing any knowledge of it as an optical instrument, is often led professionally to recommend glasses when they ought not to be used, and to fix on focal lengths entirely unfit for the purpose to which they are applied; and the mere vender of lenses and spectacles is still more frequently in the habit of profering his deleterious counsel.

Independent of these imperfections of sight, which arise from some original defect in the organ of vision, and of those accidental derangements to which persons of all ages are subjected, there is a change which takes place in the human crystalline lens, between the age of thirty and fifty, when the person begins to experience slight difficulties in reading small type or ill printed books, particularly with candle light. This imperfection of vision, at first very slight, and scarcely appreciable, arises *from a mechanical change in the condition of the lens, by which its density and refractive power, as well as its form, are altered.* This change is analogous to that which takes place in every other part of the human frame on the approach of age. It commences, in general, not uniformly throughout the whole lens, but in particular parts of it, most frequently at the margin of the lens, and is often accompanied by a partial separation of the fibres and laminæ of which it is composed.

If the human eye is not managed with peculiar care at this period, the change in the condition of the lens often runs into a cataract, or terminates in a derangement of fibres, which, though not indicated by white opacity, occasions imperfections of vision that are often mistaken for amaurosis, and other diseases. A skilful oculist, who thoroughly understands the structure of the eye, and all its optical functions, would have no difficulty, by means of nice experiments, in detecting the very portion of the lens where this change has taken place; in determining the nature and magnitude of the change which is going on;—in applying the proper remedies for stopping its progress, and in ascertaining whether it has advanced to such a state that aid can be obtained from convex or concave lenses. In such cases, lenses are often resorted to before the crystalline lens has suffered an uniform change of figure or of density; and the use of them cannot fail to aggravate the very evils which they are intended to remedy. In diseases of the lens, where the separation of fibres is confined to a small spot, but is yet of such a magnitude as to give separate coloured images of a luminous object, or irregular halos of light, it is often necessary to limit the aperture of the spectacles, so as to allow vision to be performed by the good part of the crystalline lens.

A new kind of spectacles, called *periscopic*, were introduced some years ago by Dr. Wollaston, who secured the privilege of the invention by a patent. Their principal object, as their name denotes, is to give a wider field of vision than those of the common kind, and they derive their property from always having the surface next the eye *concave*, whether the glasses are intended for short or long-sighted persons, the convexity of the outer surface being less deep than the concavity of the inner one for short-sighted persons, and more deep for long-sighted persons. These two kinds of lenses are shown at G, H, of Fig. 20. Plate CCCCXXVIII. and Figs. 25. and 26. of the same plate. There can be no doubt that the advantage of a wider field is gained in proportion as the second surface of the lens approaches to the curvature of the cornea; but it is equally certain that this advantage is gained at the expense of distinctness of vision, as such lenses increase both the aberration of colour and of figure. When we look at any object, so as to see it distinctly, we have distinct vision only over the small portion of it to which the axis of the eye is directed, all the rest of it being seen in a confused manner by oblique or indirect pencils. In reading, therefore, or in the examination of minute objects, we cannot see any advantage in the use of periscopic spectacles; but, on the other hand, when used out of doors, either in viewing a landscape, where the oblique portion of the image forms part of the picture, or in giving us warning of the oblique approach of objects, they are of essential use.

When the refraction at the interior and exterior surfaces of the cornea are equal, which happens when the eye is plunged in water, as in the case of divers, the image formed upon the retina is very confused, and spectacles are therefore necessary for the purpose of seeing objects distinctly. In order to have distinct vision, Huygens has shown that a convex glass must be used of such a radius as, when placed in water, will produce the same convergency of the rays that takes place at the junction of the cornea and the aqueous humours; and it is easy to prove, as he has done, that if the cornea is a portion of a sphere, whose diameter is 3-5ths of an inch, the lenses for divers, if doubly and equally convex, must have their convexities a portion of a spherical surface, whose diameter is 3-5ths of an inch; or if they are plano-convex, the convex surface must have a radius of 3-10ths of an inch. See Huygens' *Dioptrica*, p. 118; Smith's *Optics*, vol. ii. *Rem.* p. 10; Wollaston, *Phil. Trans.* 1813.

SECT. VII.—*On the Camera Obscura.*

The *Camera Obscura*, or the *dark chamber*, is a name given to an optical instrument invented by Baptista Porta.

If a room is made entirely dark, and a convex lens of one or more feet focal length, is placed in a hole in the window-shutter, it will form behind it, on a sheet of white paper, a beautiful picture of all the objects before it, in which will be seen all those movements and changes of colour and of position, which characterize the living picture without.

In order, however, to have this picture formed upon a horizontal table for the purpose of copying it, it is necessary to receive the rays upon a mirror inclined 45° to the horizon, as is shown in Fig. 6. where AB is the object without the window, CD the lens, GH the image that would be formed upon a vertical sheet of paper, if the plane mirror EF were not interposed, and IK the image formed upon a plate of ground glass, whose rough surface is placed uppermost. The picture may then be traced with great accuracy on the surface of the ground glass. But if it is required to throw the image upon a sheet of white paper, we have only to conceive the whole of Fig. 4. inverted, and EF placed a little nearer to CD, in order to throw IK to a greater distance, and leave room for the introduction of the hand of the artist between E and K. Fig. 4. represents the construction of the *portable camera obscura*, the outside of which is shown in Fig. 5. It consists of two square drawers, D and EF, the drawer D containing the lens at CD, and capable of being moved out or in within the tube E for the purpose of adjusting the focus of the lens to the distance of the object. The other drawer E contains the inclined mirror EF, which reflects the rays upon the ground glass G, and has a lid which turns up in order to keep off the light from the picture on the ground glass.

When it is required to draw upon the surface of paper, the camera obscura must have the form shown in Fig. 6. where AB is the lens, and CD a mirror on the outside of it, which is placed in such a manner as to reflect the landscape downwards, on the ground EF. The observer places his head through an opening on one side, and introduces his hand with the pencil through another opening, so that no light whatever may be admitted at these apertures to efface the distinctness of the picture. In camera obscuras, where only a small lens is necessary, the reflecting mirror may be dispensed with, as shown in Fig. 7. where the lens and the reflector are formed out of one piece of glass like a diagonal eye-piece. In Fig. 7. for example, A is a rectangular prism of glass with a convex surface, *a b*, fixed on one of the faces that contain the right angles. At B, the rays are first admitted on the convex surface; but, in both cases, the rays are reflected downwards by suffering total reflexion, at the plane surface *b c*, inclined 45° to *a c* and *a b*. The construction of these prismatic lenses, both for the purposes of diagonal eye-pieces and the camera obscura, have been simplified by Dr. Brewster, who gives them the form shown at C, which is nothing more than a hemispherical lens; so that there is only one flat surface to grind, and no trouble in adjusting the three angles to 90°, 45°, and 45°.

A camera obscura for public exhibition requires to be on a large scale, so that several persons may see it distinctly at the same time. Instruments of this kind are generally erected in public observatories, such as that of Greenwich, Edinburgh, and Glasgow, where three very fine camera obscuras have been fitted up.

Camera obscuras of this kind are placed on the summit of a building, as shown in Fig. 8. which represents the one erected in the observatory at Edinburgh. The lens and the mirror without it, are placed in a wide tube, which is capable of being turned round its axis vertically, by a lever CD, which, by means of an universal joint, turns a pinion, which works in the teeth of a wheel placed round the tube. By this means, the mirror EF, contained in the tube MN, when placed at an angle of 45° to the horizon, may be turned to every point of the compass, and thus reflect down the tube and through the lens, rays from all objects in and near the horizon. In order, however, to take in a wide range of objects, it is necessary to vary the inclination of the mirror to the horizon, which is done by means of a toothed segment fixed upon it, and driven by a toothed pinion at the end of the lever GH. The images of the objects formed by the lens are received on the concave surface KL, made of stucco, and having a radius equal to the focal length of the lens AB. This stucco surface is capable of being moved up and down by means of a tube or square drawer P, moving in another drawer Q, so as to adjust it for distinct vision. When the camera is to be used, it is pushed above the summit of the roof by means of the levers CD, GH, and is detained by a catch in that position. The observer then takes CD in one hand, and GH in the other, and in this way has the complete command of the tube MN, so that he can speedily direct the mirror to any external object, and exhibit its picture on the stucco surface, or, what is better, he can begin at one point of the horizon, and exhibit in succession all the various landscapes which it contains, till he returns to the point from which he set out. When the instrument is not in use, it is pulled into the inside by the levers CD, GH. These levers are fixed up at one side, and the stucco surface is preserved from dust by having a cover put upon it.

In the construction of the camera obscura, the splendour of the picture depends on various circumstances which have not hitherto been sufficiently attended to. It has been found from experience, that a common lens is preferable to the best achromatic object glass; and Dr. Wollaston has suggested the application of the periscopic principle to the lens of the camera. M. Cauchoix has found, that the most advantageous ratio of the radii of curvature is that of 5 to 8, the shortest of the two being that which is turned towards the image.

Next to the optical perfection of the image is the nature of the surface upon which it is received. When paper is employed, it should be made as smooth as possible by burnishing its surface; and when a stucco surface is used, the greatest care must be taken to remove all asperities, and make it perfectly uniform. With the view of obviating the imperfection of the ordinary opaque grounds, Dr. Brewster made a great variety of experiments. Though he did not find any white surfaces superior to those in common use, he was surprised to observe the brilliancy and distinctness with which the pictures were represented when received upon the silvered back of a looking-glass; and he gave additional perfection to the images, by removing the protuberances and roughness of the tinfoil, by carefully grinding the surface with a soft kind of hone. Notwithstanding the bluish colour of the metallic ground, white objects are represented in their true tints, and so brilliant is the colouring, and so rich the verdure of the foliage, that the image seems to surpass in beauty even the object itself. Various experiments have also been made by the same author, to discover a good *transparent surface* as a substitute for ground glass, which would permit the application of an eye-glass. The loss of light, when the image is received on ground glass, is enormous. In order to prevent this, and give brilliancy to the colouring, Dr. Brewster places another plate of glass above the ground one, and introduces between them water, or any other fluid of a different refractive power from the ground glass;—the dispersion of the light at the separating surface of the ground glass and the fluid being sufficient to detain the convergent pencils without greatly weakening their intensity. As such a ground, however, cannot be used for copying, he put a slightly opaque varnish upon the surface of a glass plate, and also upon thin squares of mica, and he found that these varnishes might be marked with the finest lines of a pencil, and that an impression of the sketch might be conveyed by the slightest pressure of the hand to a piece of paper. One of the simplest and best of all the varnishes which he used was that of milk dried upon the glass, after it had been freed entirely of its butyraceous particles. The beauty and distinctness is such, that it will even admit the application of a lens to magnify the image, and, when properly made, will receive the mark of a black lead pencil.

Sect. IX.—*On the Megascope.*

The name of megascope has been given to the camera obscura, when employed to represent, or to take copies of objects placed in front of the window, or of the lens in the portable camera obscura, and a short distance from it. In this case, the image is generally received at a distance from the lens greater than that of the object; and is consequently very much magnified. By altering the distance of the object, the size of the image may be increased or diminished at pleasure; and when the object does not reflect much light, we have it in our power to illuminate it artificially. The megascope may be made to magnify so much as fifteen times with much advantage, and is an instrument of very great use in taking correct outlines or representations of natural objects, which, from their smallness or other causes, are not susceptible of being submitted to exact mensuration. The megascope may even be employed for copying any plans or drawings on an enlarged or a reduced scale.

Sect. X.—*On the Magic Lantern.*

The magic lantern, an optical instrument invented by Athanasius Kircher, differs from the megascope only in the way in which it is fitted up, and in the purposes to which it is applied. It consists of a lens AB, Fig. 9. which forms on the wall an enlarged image of any object placed before it, and at a greater distance than its anterior principal focus. The objects used in the magic lantern, are pictures painted with transparent varnishes in the form of sliders, as shown in Fig. 10. which move through a groove in front of the lens AB. These paintings are strongly illuminated with a lamp L inclosed in a lantern, which admits no light whatever into the room, excepting what passes through the lens AB. The light of the lamp L is thrown in a condensed state upon the pictures by means of the illuminating lens CD, which is sometimes nearly hemispherical, and the illumination is still farther increased by a concave mirror MN, which throws back the light of the lamp L, that radiates in the direction LM and LN. The painting on the sliders being thus strongly illuminated, a very distinct and enlarged image of it is represented on the wall according to the principles already described; and the magnitude of the image will be to the magnitude of the object as their respective distances from the lens AB. Hence the magnifying power may be diminished or increased, by bringing the white screen that receives the image either nearer to the lantern, or removing it to a greater distance. The images in the magic lantern are much improved by substituting two lenses in place of AB, having greater focal lengths than the single lens.

The magic lantern, which for a long time was used only as an instrument for amusing children and astonishing the ignorant, has recently been fitted up for the better purpose of conveying scientific instruction; and it is now universally used by popular lecturers on astronomy for representing the phases and the motions of the heavenly bodies, all of which are minutely painted on the sliders.

The magic lantern may be employed in almost every branch of scientific instruction, where it is desirable to give a distinct and enlarged representation of phenomena to a public class. The lecturer is thus saved the trouble of carrying about with him unwieldy diagrams, which are soon destroyed by use, and rendered unfit for their intended purpose. The *Lucernal Microscope*, an instrument analogous to the magic lantern, has been fully described under the article Microscope.

Sect. XI.—*On the Phantasmagoria.*

The term phantasmagoria, or the raising of spectres, has been given to the exhibition of an optical apparatus similar to the magic lantern, which was some years ago publicly shown in this country. No description, so far as we know, of the apparatus actually used, has ever been published; but a very excellent arrangement for a phantasmagoria has been proposed by Dr. Young, which we shall describe in his own words.

"The light of the lamp A, Fig. 11. is thrown by the mirror B, and the lenses C and D, on the painted slider at E, and the magnifier F forms the image on the screen at G. This lens is fixed to a slider, which may be drawn out of the general support or box H, and when the box is drawn back on its wheels, the rod IK lowers the point K, and by means of the rod KL adjusts the slider in such a manner, that the image is always distinctly painted on the screen G. When the box advances towards the screen, in order that the images may be diminished and appear to vanish, the support of the lens F suffers the screen M to fall, and intercept a part of the light. The rod KN must be equal to IK, and the point I must be twice the focal length of the lens F before the object, L being immediately under the focus of the lens: the screen M may have a triangular opening, so as to uncover the middle of the lens only, or the light may be intercepted in any other manner.

In order to favour the deception, the sliders are made perfectly opaque, except where the figures are introduced, the glass being covered in the light parts with a more or less transparent tint, according to the effect required. Several pieces of glass may also be occasionally placed behind each other, and may be made capable of such motions as will nearly imitate the natural motions of the objects which they represent. The figures may also be drawn with water colours on thin paper, and afterwards varnished. By removing the lantern to different distances, and altering at the same time, more or less, the position of the lens, the image may be made to increase or diminish, and to become more or less distinct at pleasure, so that, to a person unaccustomed to the effects of optical instruments, the figures may appear actually to advance and retire. In reality, however, these figures become much brighter as they are rendered smaller, while in nature the imperfect transparency of the air causes them to appear fainter when they are remote than when they are near. This imperfection might be easily remedied by the interposition of some semi-opaque substance, which might gradually be caused to admit more light, as the figure became larger, or by uncovering a larger or a smaller portion of the lamp, or of its lens. Sometimes, by throwing a strong light upon an actual opaque object, or on a living person, its image is formed on the curtain, retaining its natural motions; but in this case the object must be considerably distant, otherwise the images of its nearer and remoter parts will never be sufficiently distinct at once, the refraction being either too great for the remoter, or too small for the nearer parts; and there must also be a second lens placed at a sufficient distance from the first, to allow an inverted image to be formed between them, and to throw a second picture of this image on the screen in its natural erect position, unless the object be of such a nature, that it can be inverted without inconvenience. This effect was very well exhibited at Paris by Robertson; he also combined with his pictures the shadows of living objects, which imitate tolerably well the appearance of such objects in a dark night, or by moonshine; and while the room was in complete darkness, concealed screens were probably let down in various parts of it, on which some of the images were projected; for they were sometimes actually situated over the heads of the audience." See Dr. Thomas Young's *Lectures on Nat. Phil.* vol. i. p. 426. 785.

SECT. XII.—*On the Microscope.*

Having already, under the article MICROSCOPE, given a full account of all the various forms in which single and compound microscopes are made, it remains only to explain the principles of their construction, and to add any new improvements which have been suggested since that article was written.

ART. I.—*On Refracting and Reflecting Microscopes.*

The theory of single lenses, in so far as the formation of images is concerned, has already been given in a previous chapter. We shall therefore proceed to explain the mode in which the single microscope gives distinct and enlarged vision of minute objects. Let AB. Fig. 12. be the single lens, and MN a microscopic object placed in its anterior focus; the pencil of rays MA, ME, MB, will, by Prop. XVI. p. 639, be parallel after their emergence from the lens, and likewise the pencil NA, NE, NB, and therefore, when received by the eye CD immediately behind the lens, they will form a distinct picture $m\,n$ of the object MN upon the retina of a person possessing perfect vision. If the person who uses the microscope has the imperfect vision of old age, so as to be unable to converge parallel rays, then the slightest increase in the distance of the object MN from the lens AB, will give the rays the convergency which they require. In like manner, short-sighted persons, whose eyes are unable to converge parallel rays to a focus, will obtain distinct vision through the microscope by bringing the object a little nearer the lens.

The magnifying power of the microscope arises entirely from its enabling us to view the object so much nearer the eye, than we can do by unassisted vision; for the object MN is equally magnified, if we actually hold it as near the eye, or if we look at it through a small pinhole in a card. Hence the only benefit which is derived from the lens is, to enable the eye to see *distinctly* an object placed near it. If we suppose that *five inches* is the distance at which we obtain the most distinct vision of minute objects that we wish to examine, then a lens of one inch focal length, which enables us to see the same object at the distance of *one inch* from the eye, is said to magnify *five times*, because the apparent magnitude of an object *one* inch from the eye, is *five times* greater than that of one *six* inches, as we have already explained in Sect. III. p. 749. Hence we may produce any degree of magnifying power, merely by using lenses of very small focal length, or spheres, or globules of short radii. A Table of the magnifying power of single microscopes calculated on the above principle, together with the various methods of making them, will be found in the Article MICROSCOPE.

As the difficulty of grinding lenses of an accurate spherical figure increases with the smallness of their size, and as they admit only a small pencil of rays when their size becomes minute, opticians have had recourse to a combination of lenses, which is called the *Compound Microscope.*

The compound microscope of two lenses is shown in Fig. 13. where AB is the object glass, having the microscopic object MN placed a little without its anterior focus. An image of this object will, by Prop. XVII. p. 639, be formed at $m\,n$, a considerbale distance behind the lens, and larger than the object in proportion as the distance of the object from the lens exceeds the distance of the image. If an eye-glass is now placed at EF, so that the image $m\,n$ is in its anterior focus, the rays flowing from different points of $m\,n$ will be rendered parallel, and will be converged to foci on the retina, in the manner already noticed in our account of the single microscope; the image $m\,n$ being magnified by the eye-glass EF in precisely the same manner as if EF were a single microscope; and $m\,n$ a microscopic object. The object MN is therefore doubly magnified, *first*, by an enlarged image of it $m\,n$ being formed, and, *secondly*, by this enlarged image being again enlarged by the eye-glass. If we find, therefore, the size of the image $m\,n$ in relation to the object MN, we have only to determine how much the image $m\,n$ is magnified by EF as a single microscope, and then multiplying these numbers together, the product will be the magnifying power of the double microscope. Thus let $A\,m = 6$ AM, then $m\,n$ will be $= 6$ MN, or the image $m\,n$ will be magnified *six times*. Now, if the focal length of the eye-glass EF is half an inch, its magnifying power will be $5 \times \frac{1}{2} = 10$, and consequently the lineal magnifying power, by the double microscope, will be $6 \times 10 = 60$ times; that is, an object of a given length will appear, when seen through it, sixty times longer and sixty times broader than it really is.

In these microscopes the lenses may have any relative focal length, and may be placed at any distance; for, whatever be the distance, it is easy to have the image $m\,n$ formed in the anterior focus of the eye-glass EF, by varying the distance of the object from the object glass. The proportions and focal distances of the lenses commonly used, are given under the article MICROSCOPE.

As the field of view in the double microscope is very limited, a third glass, called the field glass, is generally added, as in Fig. 14. This glass, shown at GH, receives the converging pencils of rays after refraction by the object glass, and instead of an image being formed at $m\,n$, as it would have been, had GH not been introduced, this lens hastens the convergency of these pencils, and forms a smaller image at $\mu\,\nu$, which, being in the anterior focus of the eye-glass, will be magnified in the same manner as $m\,n$ was in the double microscope. In order to increase the field, and diminish the spherical aberration, it is found advantageous to place a second eye-glass, of a less focal length, immediately behind EF, and almost in contact with it. The rules for finding the magnifying power of compound microscopes, and the methods of fitting them up and using them, have been described at great length under the article Microscope.

As an enlarged image AB, Plate CCCCXXXI. Fig. 22. of any minute object $a\,b$, may be formed by a concave mirror MN, this mirror becomes in reality a single reflecting microscope, merely by viewing with the naked eye the enlarged image AB, which may be increased to any size by causing the object $a\,b$ to approach to the mirror. The term *single reflecting* microscope is, however, usually applied to the combination of this mirror with an eye-glass, as shown in Fig. 13. where M'N' is an object placed a little without the principal focus of the mirror or speculum $\alpha\,\beta$, shown in dotted lines, and $m\,n$ the enlarged image of it formed by reflexion, and afterwards magnified by the eye-glass EF. It is obvious, from this figure, that the reflecting microscope differs in no respect from the common compound microscope, excepting that the image $m\,n$ is formed in the one by a *concave speculum*, and in the other by a *lens*. In so far as the image formed by a speculum is more free of the aberration of colour than the image formed by the lens, the reflecting microscope will be superior to the refracting one; but it is manifest, from the Figure, that the object M'N' is not so easily managed, nor so easily illuminated in the reflecting microscope, as in the refracting one. To remove this disadvantage, Professor Amici, of Modena, places the object without the tube, where it can be strongly illuminated, and reflects it to the speculum $\alpha\,\beta$, by a plane mirror, as explained under the article Microscope, to which the reader is referred for a description of other reflecting microscopes.

Art. II.—*Account of Recent Improvements on the Microscope.*

It has been remarked, by a late eminent natural philosopher, that the great obstacle to the improvement of the microscope, "arises from the different refrangibility of the rays of light, which frequently causes such a deviation from truth in the appearances of things, that many people have imagined themselves to have made surprising discoveries, and have even published them to the world; when, in fact, they have been only as many optical deceptions, owing to the unequal refractions of the rays. For this *there seems to be no remedy*, except the introduction of achromatic glasses into microscopes as well as telescopes. How far this is practicable, hath not yet been tried; but when these glasses shall be introduced, (if such introduction is practicable,) microscopes will then undoubtedly have received their ultimate degree of perfection."

The methods which have lately been proposed by Dr. Brewster for the improvement of the microscope, may be reduced to three.

1. The construction of microscopes on a large scale.
2. The diminution of the errors of refrangibility by using lenses made of coloured glass.
3. The entire removal of the errors of refrangibility, by illuminating the microscopic objects with the homogeneous light of a *Monochromatic Lamp.*

The nature and result of these improvements we shall state in his own words:

1. "I had occasion, many years ago, to point out the advantages of constructing microscopes on a scale of unusual magnitude; and I constructed one about *fifteen* feet in length, with an achromatic object glass, which produced very superior effects. Since that time, I constructed another, with a metallic reflector, which was 48 feet in length.

The advantages of large microscopes over small ones, may be considered in reference,

1. To the imperfections of the glass employed.
2. To the spherical form into which it is ground.
3. To the adjustment of the axes of the lenses.
4. To the method of illuminating the object.
5. To the examination of objects placed in cavities; and,
6. To the examination of objects whose parts are placed at different distances from the instrument.

In making this comparison, we shall suppose that the object-glass of both microscopes intercepts the same portion of the sphere of light, which diverges from the object under examination.

1st, As the veins and irregularities of glass have a definite magnitude, a lens of a small aperture will be much more liable to have its image injured by any accidental flaw, than one of a large size, and the same may be said of the small pits and scratches which often remain even after the most careful polishing.

2d, In the operation of grinding the object-glasses of small microscopes, the optician works at random, and has the power neither of giving them a correct spherical figure, nor of adjusting the axes of their opposite surfaces; whereas, in larger lenses these operations are completely under his control.

3d, One of the principal points to be attended to in the construction of compound microscopes, is the coincidence of the axes of the lenses of which it is composed. This adjustment is seldom made, and, indeed, is not very practicable when the lenses are small. In the enlarged form, however, the axes of the lenses may be made to coincide with the greatest accuracy, and consequently, the performance of the instrument greatly improved.

4th, In small microscopes, the power of illuminating the object is very limited, from its proximity to the instrument. The light which it would naturally receive, is obstructed by the head of the observer, and by the body of the microscope; and when the object is perfectly opaque, it is almost impossible to throw upon it the requisite degree of light. In large microscopes, on the contrary, where the object is *one*, or *two*, or even *three* feet from the object-lens, we may project upon it any quantity of light that we please.

5th, The ordinary microscopes, both single and compound, are incapable of being applied to objects placed in a cavity, or in the interior of a transparent crystal; but in large microscopes, the depth of the cavity, and the thickness of the crystal, bear no sensible proportion to the distance of the object from the microscope; and the cavity, or any object which it includes, may be seen to the greatest advantage.

6th, In viewing an object of perceptible thickness, such as a fly, through the compound microscope, it is impossible to see the near and the remote parts at the same time, so that a number of successive adjustments are necessary; and even then we are imperfectly acquainted with its general form and outline. In large microscopes, however, the thickness of the object bears a very slight proportion to the conjugate focal distances of the object-lens, so that the instrument may at once be adjusted to all the parts of it that are within the field of view.

When the object to be examined is an optical structure, such as that exhibited by plates of amethyst, the ordinary microscope is entirely useless, as the figure to be observed is produced by the action of every point of the transparent plate. When the microscope is large, however, the figure is seen with as much distinctness as if it had been formed by a plate of no other dimensions but length and breadth."—*Edin. Phil. Journ.* vol. vi. p. 104.

2. Having had occasion to examine some delicate vegetable structures with high magnifying powers, Dr. Brewster experienced very great assistance in using lenses made of *green* or *red* glass, which absorbed almost all the most refrangible rays of the spectrum, and therefore gave a distinctness and precision of outline which could not be obtained from colourless lenses. He found, however, from many experiments, that the advantage thus gained, though of very considerable amount, had a limit in green glasses; and that it was only with lenses made of red glass, which absorbed all the rays excepting the extreme red, that the principle could be pushed to a high degree of perfection. The great quantity of light, however, which was extinguished before the extreme red rays were completely insulated, rendered them very absorbent, being of use principally when the outline of an object was to be observed. Had it been practicable to insulate the *yellow*, or the *most luminous* rays of the spectrum, as completely as the red, the advantages would have been very great; but no glass could be found with such a property.

3. Not content with the advantage, by no means equivocal, which was obtained from the use of coloured lenses, he endeavoured to obtain from the combustion of inflammable substances a *homogeneous flame for illuminating microscopic objects.*

"It had long been known," says he, "that a great quantity of homogeneous light was created by placing salt or nitre in the white flame of a candle, or in the blue and white flame of burning alcohol.* A light, however, generated in this manner, was more fitted for a casual experiment, than for a permanent source of illumination; and as insalubrious vapours are disengaged during the combustion of these salts, I did not avail myself of this method of obtaining yellow light.

After numerous experiments, attended with much trouble and disappointment, I found *that almost all bodies in which the combustion was imperfect, such as paper, linen, cotton, &c. gave a light in which the homogeneous yellow rays predominated;* that the quantity of yellow light increased with the humidity of these bodies; and that a great proportion of the same light was generated, when various flames were urged mechanically by a blowpipe or a pair of bellows.

As the yellow rays seemed to be the product of an imperfect combustion, I conceived that alcohol diluted with water would produce them in greater abundance than when it was in a state of purity, and upon making the experiment, I found it to succeed beyond my most sanguine expectations. The whole of the flame, with the exception of a small portion of blue light, was a *fine homogeneous yellow*, which, when analysed by the prism, exhibited traces of green and blue, but not a single ray of red or orange light. The green and blue rays which accompanied the yellow flame had comparatively so little intensity, that they disappeared in the processes of illuminating and magnifying the object under examination; and, even if they had existed in greater abundance, it was quite easy to absorb them at once by the intervention of a plate of the palest yellow glass, and thus render the lamp perfectly monochromatic.

From many experiments on the combustion of diluted alcohol, I found that the discharge of yellow light depended greatly on the nature of the wick, and on the rapidity with which the fluid was converted into vapour. A piece of sponge, with a number of projecting points, answered the purpose of a wick better than any other substance, and the extrication of the yellow light became more copious, by placing a common spirit-lamp below the burner of the other. In order to obtain a very strong light for occasional purposes, I connected with the top of the burner a frame of wire-gauze, which, by moving vertically round a hinge, or by a motion to one side, could be placed in a horizontal position about half an inch above the wick. As soon as it had become red-hot, it was made to descend into contact with the sponge, when it converted the alcohol rapidly into vapour, and produced an abundant discharge of yellow light.

If a permanently strong light is required, I found it preferable to dispense entirely with the use of the wick, and to allow the diluted alcohol to descend slowly from the rim into the bottom of a concave dish of platinum, kept very hot by a spirit-lamp placed beneath it. The bottom of the dish is made with a number of projecting eminences, in order that the film of fluid which rests upon it may be exposed at many points to the action of the heated surface. After the lamp has burned for some time, a portion of unevaporated water, mixed with a small quantity of alcohol, will remain at the bottom of the dish, in a state unfit for combustion. This water may be taken up by a sponge, or it might be prevented from accumulating, by having a fountain of pure alcohol, from which the exhausted strength of the diluted fluid could be renewed.

The *Monochromatic Lamp* being thus completed, I lost no time in applying it to the illumination of microscopic objects. The effect which it produced far exceeded my expectations. The images of the most minute vegetable structures were precise and distinct, and the vision in every respect more perfect than it could have been, had all the lenses of the microscope been made completely achromatic by the most skillul artist. The errors which arise from the different refrangibility of light being removed from microscopical observations, I was enabled to enlarge considerably the aperture of the object-glass, till the image became sensibly affected by the errors of spherical aberration. In order to diminish these as much as possible, the object-glass should consist of an annular portion of the lens that gives a minimum spherical aberration, and while its surfaces are nicely centred, their common axis should be adjusted so as to coincide accurately with that of the other lenses. The optician, however, will probably be induced to exert his ingenuity in the formation of elliptical and hyperbolical lenses, which, since the days of Descartes and Huygens, have existed only in optical theories, and thus remove the only imperfection which still attaches to the microscope." See *Edinburgh Transactions*, vol. ix.

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* *Edinburgh Physical and Literary Essays*, vol. ii. p. 34; and Dr. Thomas Young's *Nat. Phil.* vol. ii. p. 438. Mr. Herschel informs us, that *Sulphur* in a certain stage of its combustion produces a homogeneous yellow light.

A method of diminishing the spherical aberration has been brought forward by the same author; but it has not yet been published.

SECT. XII. *On the Telescope.*

The word telescope, from τηλε, *at a distance*, and σκοπεω, *to see*, is an instrument for seeing objects placed at a distance, and is perhaps one of the most valuable and remarkable instruments with which science has presented us for gratifying our curiosity and extending our knowledge. There are three kinds of telescopes, viz. the *Common Refracting Telescope*, the *Reflecting Telescope*, and the *Achromatic Telescope*, which we shall describe in their order.

ART. I.—*On the Common Refracting Telescope.*

1. *On the Astronomical Telescope.*—The astronomical telescope, which was invented by Kepler, is represented in Fig. 15. It consists of a convex glass AB, called the *object-glass*, and of another convex lens CD, of much shorter focal distance, called the *eye-glass*. The object-glass AB is screwed into the end of a tube, a little longer than its focal distance, and the *eye-glass* CD is fixed into a small tube, which can be moved out and in at the other extremity of the longer tube. When such an instrument is directed to a distant object MN, and distinct vision obtained by adjusting the tube containing the eye-glass, the magnified image will be formed in the following manner. The rays MA, MB, and NA, NB, will converge by the refraction of the lens AB, to foci at n and m, and will there paint an inverted image $n\,m$ of the object MN, at a distance from the object-glass a little greater than its principal focal length, as the object is not infinitely distant. This inverted image being in the anterior focus of the eye-glass CD, the pencils of rays n C, m D, rendered parallel at their emergence from the eye-glass CD, will enter the eye, and form an erect image $\mu\nu$, of the object MN, upon the retina. Hence it follows, (see p. 749,) that through such a telescope all objects will be seen *inverted*, and as this is not considered a disadvantage to astronomers, it has, on this account, received the name of the *astronomical telescope*.

In order to find the magnifying power of this or of any other telescope, we must compare the apparent magnitude of the object as seen by the naked eye, with its apparent magnitude as seen through the telescope. As the distance of the object is always very great, compared with the length of the telescope, the angle MEN which the object MN subtends at the object-glass, may be considered as a correct measure of its apparent magnitude. Now, the real angle under which the magnified image is seen by the eye, is $\mathrm{C}\,e\,\mathrm{D}$, or $\mathrm{G}\,e\,\mathrm{H} = n\,\varepsilon\,m$, which is to MEN or its equal n EM, as EF : ε F, that is, as the focal distance of the object-glass is to the focal distance of the eye-glass. Hence the magnifying power, or the number of times that the apparent magnitude of the object MN is increased by the telescope, will be obtained by dividing the focal length of the object-glass by that of the eye-glass. If the former is five feet, and the other one inch, the magnifying power will be sixty times, or an object of sixty miles distance will appear of the same magnitude as if it were brought within one mile of the eye.

In the astronomical telescope, the extent of the field of view, or the part of an object which can be seen at once through the telescope, depends on the diameter of the eye-glass CD, and not on that of the object-glass; for if the eye-glass CD were too small to receive the rays C n, D m, the extremities MN of the object could not be seen at all. The only effect of enlarging the object-glass is, to produce a greater degree of light, by receiving a larger cone of the rays flowing from each point of the object.

2. *Terrestrial Telescope.*—Although the inversion of the image is of no consequence in astronomical observations, yet, in viewing land objects, an erect view of the object is essentially necessary. In order to produce this effect, we must use three eye-glasses, viz. CD, C′D, C″D″, Fig. 16. which are generally made of the same focal lengths, and placed at distances double of their focal lengths. The progress of the rays is exactly the same in this telescope as in the last, as far as L, where the two pencils CL, DL, consisting of parallel rays, cross one another at L, in the anterior focus of C′D′. These parallel rays falling on the second eye-glass C′D′, are converged to foci at n' m', so as to form an erect image at n' m', and the pencils m' C″, n' D″, flowing from this image, will emerge parallel from the third eye-glass C″D″, and, crossing one another at e, will form a distinct inverted image $\mu\nu$ of the object MN on the retina. Hence it follows, (see p. 749,) that the object will be seen erect through the telescope.

As the lenses C′D′, C″D″ are of equal focal lengths, and the image n' m' equidistant from them, it is obvious that the angle $\mathrm{C}''\,e\,\mathrm{D}''$, under which the magnified image m' n' of the object is seen, is equal to CLD, the same angle under which it would have been seen had there been only one eye-glass CD. Hence the magnifying power of such a telescope is equal to the focal length of the object-glass, divided by the focal length of one of its three equal eye-glasses.

In this telescope a diaphragm, or limiting circular aperture, is placed at L, to exclude extraneous light, and of such a diameter as just to admit the extreme rays. Another, but larger diaphragm, or *field-bar*, as it is called, is placed at EF, to give a distinct outline to the field of view.

3. *Galilean telescope.*—The Galilean telescope received its name from its having been first used by Galileo, and differs in no respect from the astronomical telescope, excepting in the substitution of a concave eye-glass CD, Fig. 17. in place of a convex eye-glass. This eye-glass is placed between the object-glass AB, and its principal focus, and receives the converging rays before they form the image $m\,n$. If the concave eye-glass CD is placed so that the image that would be formed at $m\,n$ is in its principal focus, it will render parallel the rays tending to m and n, and consequently these rays will be converged to points on the retina, and there form a distinct and inverted image $\mu\,\nu$. Hence it follows, (see

p. 749.) that this telescope will give an erect view of the object MN.

The magnifying power of this telescope will be equal to the focal length of the object-glass divided by that of the eye-glass; for the extreme pencils which were formerly made to converge to e in the astronomical telescope, and form the angle C e D, or $\mu\, e\, \nu$, are now made to diverge, or form the angle μ F ν.

This telescope possesses some advantages over the astronomical telescope. 1st, It has the same magnifying power under a shorter length, the length of the telescope being equal to the difference of the focal lengths of the object-glass and the eye-glass, whereas in the astronomical telescope it is equal to their sum. 2d, It gives us an erect view of the object without using three eye-glasses, which must occasion a great loss of light, even if the lenses are ground to a perfect figure. 3d, There is less absorption of light, in consequence of the rays passing through a less thickness of eye-glass; and 4th, the vision is much more perfect; a circumstance which no doubt arises from the rays never coming to a positive focus, and never crossing one another in a condensed state during the whole of their progress through the instrument. For it cannot be doubted that the rays of light, notwithstanding their extreme tenuity, interfere with one another, and produce an indistinctness of vision.

The disadvantages of the Galilean telescope arise solely from its limited field of view. Since the lateral pencils now diverge from the axis of the lenses, the field of view depends solely on the diameter of the pupil of the eye, and as this cannot be increased at pleasure, there are no means of remedying this evil in the Galilean telescope.

The imperfections of the common refracting telescope, with a single object-glass, have been already pointed out in Prop. IX. p. 670, and are so great, that, in order to obtain a high magnifying power, it is necessary to use object-glasses of a great focal length, such as those of Huygens and others, which are mentioned in the History of Optics, p. 601.

It follows from the theory of aberration already given, and it has also been demonstrated by Huygens, that the apparent indistinctness of a given object seen through a refracting telescope, is directly as the area of the object-glass, and inversely as the square of the focal distance of the eye-glass. In like manner it may be shown, that the apparent brightness of a given object is directly as the square of the lineal aperture of the object-glass, and inversely as the square of its magnifying power. Hence it follows, that, in refracting telescopes of different lengths, a given object will appear equally bright, and equally distinct, when their linear apertures, and the focal distances of the eye-glasses, are as the square roots of the focal distances of their object-glasses; and consequently their magnifying powers will be as the square roots of the focal distances of the object-glasses.

Upon these principles we may compute the focal distance of the eye-glasses suited to object-glasses of different focal lengths, provided we have once ascertained by experiment the highest magnifying power that an object-glass of a given focal length will bear with perfect distinctness. One of Huygens' best telescopes, 30 feet long, had an aperture of three inches, with an eye-glass three inches and $\frac{3}{10}$ in focal length, and from this telescope, as a standard, the editors of his Dioptrics computed the Table given in p. 211 of that work, and reprinted by Dr. Smith in the 148th page of the first volume of his Optics. It appears, however, from the *Astroscopia Compendiaria* of Huygens, that he possessed a telescope superior even to this, whose object-glass was 34 feet in focal length, and which had a magnifying power of 163 times, with an eye-glass of $2\frac{1}{2}$ inches focal length.* A Table, calculated upon the supposition that telescopes may be made like this, has been given by some writers; (see Ferguson's *Lectures*, App. vol. ii.) but we prefer taking the standard just mentioned, as Huygens, in the same paper, mentions a telescope of 30 feet and 3 inches of aperture, as the standard one.

As the following table is calculated in Rhinland measure, we have not thought it necessary to recompute it in English feet and inches; but as the English foot is to the Rhinland foot as 139 to 135, we have only to reduce the two middle columns in the ratio of $\sqrt{139}$ to $\sqrt{135}$, that is nearly in the ratio of 139 to 137, or about $\frac{1}{69}$th or $\frac{1}{70}$th part of the whole.

Table of the Apertures, Focal Lengths, and Magnifying Powers of Common Refracting Telescopes.

Length of the Telescope, or Focal Distance of the Object-Glass.	Linear Aperture, or Diameter of the Object-Glass.		Focal Length of the Eye-Glass.		Linear Magnifying Powers.
Feet.	Inches.	Hundredths.	Inches.	Hundredths.	Number of Times.
1	0	55	0	61	20
2	0	77	0	85	28
3	0	95	1	05	34
4	1	09	1	20	40
5	1	23	1	35	44
6	1	34	1	47	49
7	1	45	1	60	53
8	1	55	1	71	56
9	1	64	1	80	60
10	1	73	1	90	63
13	1	97	2	17	72
15	2	12	2	33	77
20	2	45	2	70	89
25	2	74	3	01	100
30	3	00	3	30	109
35	3	24	3	56	118
40	3	46	3	81	126
45	3	67	4	04	133
50	3	87	4	26	141
55	4	06	4	47	148
60	4	24	4	66	154
65	4	42	4	86	161
70	4	58	5	04	166
75	4	74	5	21	172
80	4	90	5	39	178

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* Hugenii *Opera Varia*, tom. i. p. 262. Huygens does not mention the aperture.

Length of the Telescope, or Focal Distance of the Object-Glass.	Linear Aperture, or Diameter of the Object-Glass.		Focal Length of the Eye-Glass.		Linear Magnifying Powers.
Feet.	Inches.	Hundredths.	Inches.	Hundredths.	Number of Times.
85	5	05	5	56	183
90	5	20	5	72	189
95	5	34	5	87	194
100	5	48	6	03	199
110	5	74	6	31	209
120	6	00	6	60	218
130	6	25	6	88	227
140	6	48	7	13	235
150	6	71	7	38	244
160	6	93	7	62	252
170	7	14	7	85	259
180	7	35	8	09	267
190	7	55	8	31	274
200	7	75	8	53	281
220	8	12	8	93	295
240	8	48	8	33	308
260	8	83	9	71	321
280	9	16	10	08	333
300	9	49	10	44	345
320	9	80	10	78	356
340	10	10	11	11	367
360	10	39	11	43	378
380	10	68	11	75	388
400	10	95	12	05	398
500	12	25	13	47	445
600	13	42	14	76	488

In order to render the common refracting telescope as perfect as possible, without making it achromatic, the spherical aberration should be reduced by grinding the exterior surface of the object-glass to a radius equal to *five-ninths* of its focal length, and the interior surface to a radius equal to *five times* its focal length. In the eye-glasses, the radius of the surface next the object, should be *nine* times its focal length, and that of the surface next the eye, *three-fifths* of the same distance.

When the object to which the telescope is directed is luminous, such as the Sun, and Jupiter, and Venus, when they are near the earth, considerable advantage may be derived from the use of red or green eye-glasses, or, if the telescope is large, from the interposition of plane pieces of green and red glass.

Art. II.– *On Reflecting Telescopes.*

The great difficulty of managing refracting telescopes when of great length, notwithstanding the ingenious contrivance of Huygens to use them without tubes, and the impossibility of procuring a higher magnifying power than 500 times, even by making them 600 feet long, induced philosophers to employ the principle of reflexion for the purpose of shortening this valuable instrument.

1. *On the Gregorian Telescope.*

The first successful attempt to effect this desirable purpose was made by our countryman, James Gregory, previous to 1663, as we have already related in our History of Optics, (p. 601.) The instrument which he invented is represented in Fig. 1. where AB is a perforated concave metallic speculum, which is either a portion of a sphere or of a prolate spheroid, in one of whose foci is situated the distant object MN, while the image of the object is formed in its other focus AB. In front of this large speculum is placed a smaller concave speculum S, which isalso part of a prolate spheroid, and which, by means of the arm SQ, which carries it, and the screwed rod WQ, may be made to approach to the great speculum AB, or to recede from it. Into the end of the tube TTTT, in which these specula are placed, is screwed an eye tube *t q r t*, containing an eye-piece of one or two lenses, placed at a permanent distance from the speculum AB, and from each other. If we now suppose the rays RA, RB, to issue nearly parallel from the extremities M and N of the distant object MN, viz. RA from N, and RB from M, these rays will be reflected in a converging state to foci at *n* and *m*, and will there form an inverted image *m n* of the object MN, (see Prop. X. p. 659, and Prop. XIV. p. 660.) If *f* is the principal focus of the small speculum S, then rays flowing from any point of the image *m n*, will form an erect image behind the large speculum AB, and somewhere between C and D, the rays which form the image passing through the aperture VX in the large speculum The rays which tend to form this image are intercepted by the first eye-glass C, and made to converge so as to form an erectage $\mu\pi$ of the object in the focus of the second eye-glass D, by which they are rendered parallel, and in that state enter the eye at *e*. If the small speculum S is brought nearer the image *m n*, the image formed behind C and D, independent of the eye-glasses, will recede from the great speculum; and, on the contrary, if the speculum S is made to recede from the image *m n*, the image between C and D will approach to the great speculum. Hence, by the motion of the small speculum S, we can easily change the convergency of the rays till the first lens C forms a distinct image of the object in the anterior focus of the second eye-glass D.

In order to determine the magnifying power of the Gregorian telescope, let G be the centre of its reflecting surface; and let us suppose, for the present, that the lens C is removed, and that $\mu\pi$ is the image formed by the small speculum S, and viewed by the single eye-glass D. Since G *n* is a ray passing through the centre of the speculum, and the extremity *n* of the image, it must come from the extremity of the object, and form with the axis PD an angle DG *n*, equal to the angle subtended by half the object MP at the point G, which may be considered as the angle which the object MP subtends at the eye of the observer. The angle which the corresponding part of the magnified image subtends at the eye, or at *e*, is $ce\,\mathrm{D} = \mu\,\mathrm{D}\,\pi$. Now, when the angles are small, $\mu\,\mathrm{D}\,\pi : \mu\,g\,\pi$ (or $\mathrm{F}\,g$) $= g\,\pi : \pi\,\mathrm{D}$; and also $\mathrm{F}\,g\,m : \mathrm{FG}\,m = \mathrm{GF} : g\,\mathrm{F}$, and by composition $\mu\,\mathrm{D}\,\pi : \mathrm{FG}\,m = g\,\pi \times \mathrm{GF} : \pi\,\mathrm{D} \times g\,\mathrm{F}$, that is, the apparent magnitude of the object MP when seen through the telescope, is to its apparent magnitude when seen by the naked eye, as $g\,\pi \times \mathrm{GF} : \pi\,\mathrm{D} \times g\,\mathrm{F}$; but by Prop IV. p. 656, $\mathrm{F}f : f\,g = \mathrm{GF} : \pi\,g$; and, consequently, by inversion, $f\,g \times \mathrm{FG} : \mathrm{F}f \times \pi\,\mathrm{D} = \pi\,g \times \mathrm{FG} : \pi\,\mathrm{D} \times \mathrm{F}\,g$, that is, the apparent magnitude of the object is to the apparent magnitude of the image as $f\,g \times \mathrm{FG} : \mathrm{F}f \times \pi\,\mathrm{D} = \frac{f\,g \times \mathrm{FG}}{\mathrm{F}f \times \pi\,\mathrm{D}}$; but $\mathrm{S}\,\pi : \mathrm{S}\,f = f\,g : \mathrm{F}f$, hence $\frac{\mathrm{S}\,\pi}{\mathrm{S}f} =$

$\frac{fg}{Ff}$; and, consequently, we have, by substitution, the magnifying power $=\frac{S\pi \times FG}{Sf \times \pi D}$, that is *Multiply the focal distance of the great speculum by the distance of the small mirror from the image next the eye, (as formed in the anterior focus of the convex eye-glass) and multiply also the focal distance of the small speculum by the focal distance of the eye-glass; then the quotient arising from dividing the former product by the latter will be the magnifying power required.*

The following Table of the dimensions and magnifying powers of Gregorian telescopes has been computed by Dr. Smith, from an excellent standard telescope of Short's, which is the second in the Table, with a focal length of 9.6 inches, and a magnifying power of 60.

Table of the Dimensions, Focal Lengths, and Apertures of Gregorian Telescopes, as constructed by Mr. Short, according to the computations of Dr. Smith.

Focal length of the great Speculum.	Breadth of the great Speculum.	Breadth of the small Speculum, and of the Hole in the large one.	Focal length of the small Speculum.	Distance between the two Specula.	Distance between the large Speculum and the Plane Surface of the first Eye-glass.	Focal distance of the first Eye-glass, or that next the Metals.	Focal distance of the second Eye glass, or that next the Eye.	Distance between the Plane Sides of the two Lenses.	Distance between the second Eye-glass and the small Eye Hole.	Diameter of the Diaphragm placed in the anterior Focus of the Lens.	Magnifying Power.
Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Times.
5.65	1.55	0.31	1.11	6 78	1 76	2.45	0.81	1.63	0.41	0 27	39 69
9.60	2.30	0.40	1.50	11.25	3 36	3.13	1 04	2.09	0.52	0 35	60.
15 50	3.30	0.50	2.15	17.84	3.95	5.97	1.31	2.63	0.66	0.44	86 46
36 00	6.26	0.65	3.43	39.72	1.44	5.12	1.71	3.41	0.85	0.57	165.02
60 00	9.21	0.83	5.01	65.39	2 78	6.43	2.14	4.29	1.07	0.72	242.94
1	2	3	4	5	6	7	8	9	10	11	12

The following Table, calculated by Mr. Short, embraces a great variety of focal lengths, and contains the different powers which he applied, together with the prices of the instruments.

Number.	Focal length in Inches.	Diameter of Apperture in Inches.	Magnifying Powers.	Prices in Guineas.
1	3	1 1	1 Power of . . . 18 times	3
2	4½	1.3	1 25	4
3	7	1.9	1 40	6
4	9½	2.5	2 . . . 40 and 60	8
5	12	3.0	2 . . . 55 and 85	10
6	12	3.0	4 . . 35, 55, 85, and 110	14
7	18	3.8	4 . . 55, 95, 130, and 200	20
8	24	4.5	4 . 90, 150, 230, and 300	35
9	36	6.3	4 . 100, 200, 300, and 400	75
10	48	7.6	4 . 120, 260, 380, and 500	100
11	72	12.2	4 . 200, 400, 600, and 800	300
12	144	18.0	4 . 300, 600, 900, and 1200	800

As the extent of the field of view depends on the diameter of the eye-glass, and as an eye-glass of sufficient breadth would require to be very thick to give the requisite magnifying power, it is usual to substitute what is called the Huygenian eye-piece, consisting of two plano-convex lenses C, D, with their plane surfaces turned towards the eye. By this means the visible area or field of view is increased and the requisite power is obtained, without using very deep curvatures.

In the following Table, Dr. Smith[*] has given the positions and focal distances of these two lenses, together with the semi-diameter of the field-bar in the anterior focus of the lens next the eye, and the distance of the eye-hole, from the second lens, as corresponding to different focal lengths of the great speculum.

Focal length of the great Speculum.	Distance of the Plane Surface of the first Lens behind the Vertex of the great Speculum.	Distance between the Plane surfaces of the two Lenses.	Focal length of first Lens reckoned from the Plane Surface.	Focal length of second Lens reckoned from the Plane surface.	Distance of the Eye-Hole behind Plane Surface of the second Lens.	Semi-Diameter of the Field Bar or Diaphragm.
Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
5 65	1.764	1.631	2.446	0.815	0.408	0.136
9.60	3.358	2 087	3.130	1.043	0.522	0.174
15.50	5.975	2 631	3.946	1.315	0.658	0.220
36.00	1.439	3.415	5.122	1.707	0.854	0.286
60.00	2.783	4.289	6.434	2.144	1.072	0.359

As it is of the greatest Importance to the performance of Gregorian telescopes, to give a proper diameter to the eye-hole, and to place it at its proper distance from the eye-glass, we shall add to the information in the preceding Table Mr. Edwards' rules for this purpose.

If there is only one eye-glass, then the distance of the small hole behind A should be as nearly as possible equal to its focal length; but in the compound Huygenian eye-piece the distance of the eye-hole may be thus found: Multiply the difference between the focal distances of the glass next to the speculum, and the distance of the two eye-glasses, by the focal distance of the glass nearest to the eye, and divide this product by the sum of the focal distances of the two lenses lessened by their distance, and the quotient will be the compound focal distance required. Thus, if the focal distance of the lens next the speculum is three inches, that of the lens next the eye one inch, and their distance ten inches, then the compound focal distance from the eye-glass will be

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[*] *Optics*, vol. ii. Rem. p. 105.

$$\frac{\overline{3-2}+1}{3+2}=\tfrac{1}{2}\text{ an inch.}$$

The diameter of the eye-hole is always equal to the quotient obtained by dividing the diameter of the great speculum by the magnifying power of the telescope.

As the measures of the focal lengths and distances of the lenses are not easily determined with requisite accuracy, Mr. Edwards considers it necessary to obtain, from direct experiment, a more accurate determination of the place and size of the eye-hole after it has been found by the preceding rule. With a small convex glass, says he, of an inch, or an inch and a half, focal distance, view the picture of the large mirror in the eye-hole; hold the convex glass as steady as you can in one hand, and move your eye upwards and downwards towards the right hand or towards the left; then if the picture of the large speculum in the eye-hole has a motion in the *same direction* with the eye, the focus of the eye-glass, whether single or compound, is between the eye-hole and the eye-glass; but if the picture of the great speculum in the eye-hole appears to move *contrary* to the motion of the eye, then the true focus is between the eye and the eye-hole. In the former case the eye-hole must be brought *nearer* to the eye-glass, in the latter case it must be removed *farther* from it, till you perceive the picture of the great mirror become stationary, or without any motion, in whatever direction the eye is moved; for then only the eye-hole is most *accurately* in the focus of the single or compound eye-glass.

The diameter of the eye-hole may also be determined exactly, by viewing with a small convex glass held in the hand, as in the preceding operation, the exact size of the picture of the great speculum in the place of the eye-hole, determined accurately by the foregoing direction. If the area of the eye-hole appears a small degree larger than the area of the emergent pencil of rays, or the picture of the great speculum, then it is sufficiently large to transmit all the rays of light which come from the great speculum. But if the area of the eye-hole is found to be less than the area of the picture of the great speculum, the eye-hole must be enlarged till its diameter shall be found equal to, or rather a little larger than the diameter of the emergent pencil of rays.

Mr. Edwards, who had much practical experience in the construction of Gregorian telescopes, found that *crown glass*, such as is used for the convex lenses of achromatic object-glasses, was preferable to flint-glass for eye-glasses, and that those pieces were the best, which, when laid on a sheet of white paper, gave a *bluish green*, and not a *yellowish green* tinge. The dingy or yellowish appearance of objects in reflecting telescopes, which arises either from an imperfect polish, or from the metal not being sufficiently white, is entirely destroyed when the eye-glasses are made of the crown glass just mentioned, and objects appear of their own natural colour.

In order to try the figure of the great speculum, Mr. Edwards places at the distance of 50 or 100 yards, a white circle of half an inch or an inch in diameter, with a pretty broad black margin. He then adjusts the telescope, so as to show it as distinctly as possible, and by turning the milled head W. Fig. 1. either to the right or to the left, he observes a regular dark haze round the circle, becoming broader and broader as the milled head is turned. If the haze is more distinct when the milled head is turned to the right from the place of distinct vision than when it is turned to the left, the figure of the great speculum is *spherical*, and if the contrary takes place, it is *hyperbolical*, or beyond the parabola. But if the haze and the edges of it are equally distinct on both sides of the true focus, or point of distinct vision, then the great speculum has a true parabolic figure.

As the centering of the specula, and the lenses of a Gregorian telescope, are essentially necessary to its correct performance, Mr. Edwards has given the following minute directions for accomplishing this object.

1. Extend two fine threads or wires across the aperture of the tube at right angles, so as to intersect each other exactly in the axis of the telescope; before the arm is finally fastened to the slider, place it in the tube, and through the eye-piece (without glasses) the intersection of the cross-wires must be seen exactly in the centre of the hole of the arm. When this exactness is obtained, let the arm be firmly rivetted and soldered to the slider.

2. Divide the circumference of the mouth-piece of the tube of the telescope into four equal parts. Provide a circle of pasteboard, about one-half or two-thirds of the diameter of the mouth of the tube. Procure also a narrow strip of wood, whose length is exactly equal to the inside diameter of the mouth of the tube; divide it into two equal parts, and to this middle point fasten the centre of the pasteboard circle by a small pin. Apply now this small apparatus to the two opposite marks made on the mouth of the tube; by this means the centre of the pasteboard circle will coincide with the centre of the tube. Care also must be taken that the pasteboard circle be in the same plane with the mouth of the telescope, or, which is the same thing, at right angles to its axis; which is easily effected by applying the edge of a ruler across the mouth of the telescope, and by making any of the diameters of the pasteboard circle touch the edge of the rule. Take now the eye-glasses from the eye-tube, and screw that tube, without its glasses, in its proper place; direct then the mouth of the telescope towards a window or the sky, apply your eye to the small hole in the eye-tube, and observe whether the ring of light in the small mirror is exactly of the same breadth in every part of it, which will always be the case when the small metal is parallel to the great speculum, in all other positions of the small speculum, the ring of light in it (which is only the reflected image of that part of the great mirror which is not hid by the pasteboard circle) will appear of different breadths in different parts of its circumference; adjust now the small mirror by the three screws at its back, till the ring of light

appears, in every part, exactly of the same uniform breadth; and thus, by a few trials, the face of the small metal may easily be placed parallel to the face of the great speculum.

3. Put the circular pasteboard on the mouth of the tube, as before; then apply the eye to the eye-hole, the eye-glasses being removed, and observe whether the outer edge of the ring of light in the small mirror, when adjusted by the preceding rule, is equidistant in every part of its circumference from the edge of the small metal. In such case the centre of the small mirror is coincident with the axis of the telescope; but if the outer edge of the ring of light in the small speculum is nearer to the edge of it in some parts of its circumference than in others, or, in other words, if the dark part surrounding the ring of light in the small speculum has not the same breadth in every part of its circumference, then the centre of the small metal is not coincident with the axis of the tube, but must be raised higher or depressed lower, must be put towards the right hand or towards the left, as shall appear necessary. The easiest method to perform this is, to make the screw, which goes through the hole in the upright stem of brass which carries the small metal with a broad shoulder to it, and to make the hole in the centre of the brass stem pretty large, but not so large as the shoulder of the screw, by which means the small mirror may be raised or depressed, may be placed a little to the right hand or towards the left, as is found to be most proper, and may be retained in any of those positions by the three small screws that bear against the back of the small speculum. This and the preceding adjustment must be repeated by trials, till the ring of light in the small mirror is of one uniform breadth in every part of its circumference, and at the same time, the outer edge of the ring of light is equidistant from the edge of the small metal; for then, and then only, the face of the small mirror is parallel to the face of the great speculum, and, at the same time, its centre is coincident with the axis of the tube; or the centres of the eye-glasses, and the centres of the great and small specula are in one right line.

When the small mirror has been adjusted, by the preceding directions, those two adjustments may be examined and rectified to the utmost degree of precision by the following method:

Put up a circle of half an inch or an inch in diameter, with a broad black margin to its circumference, at the distance of fifty or a hundred yards from the telescope. Turn the screw which carries the brass stem and the small mirror nearer to, or farther from, the great speculum, and you will observe, if the metals are centered very well, the margin of the circle will appear to become less and less, so as to form continually a less circle, till at last, as you continue turning the screw, it will terminate in a black spot in the middle of the true circle, (which will still continue visible,) with a large broad and black haze round it, equally broad in every part of it. If the black spot appears on the margin of the true circle, and consequently the black haze is not equally broad round the true circle, then the mirrors are not exquisitely centered, but the small metal must be adjusted by the three small screws at the back of it, by screwing up, in a very small degree, the small screw which is diametrically *opposite* to the black spot, or on the other side of the centre of the circle on whose margin[*] the spot appears. When the metals are found to be exquisitely centered, fasten the three small screws at the back of the small speculum with common soft solder, to prevent them from drawing, or giving way. Put up now a watch paper, or any other printed paper, with letters or figures upon it of different dimensions, some of which should be very small, at the distance of at least sixty times the focal length of the great speculum from the telescope. Turn the large mirror in its cell, about the eighth part of a revolution each time, and observe in which of those positions the minute figures or letters upon the paper are most distinct: Mark, then, with a black stroke, the upper part of the back of the great speculum, and a corresponding part upon the inside of the brass tube, adjoining to the black stroke on the back of the mirror; by which means, if the great speculum is taken out of its cell at any time, it may easily be replaced exactly in the same position. The mirrors may also be examined by means of any of the fixed stars, particularly by those of the *first* magnitude; for if the mirrors are truly centered, and adjusted to their best position, a fixed star, when made indistinct by the adjusting screw on the side of the tube, should always appear in reflecting telescopes, as a truly *round* circle of fire with a black spot exactly in its centre; and when the telescope is adjusted to distinct vision, the star should appear, if the telescope is excellent, and the state of the air favourable, exactly *round*, and totally free from all irradiations, or false rays and glare. Indeed, I can assert from experience, that no object is so proper to determine the excellence of telescopes as the fixed stars; as the least irregularity in the figure of the metals in reflecting telescopes, or of the object-glass in achromatics, is rendered by them exceedingly conspicuous by a false glare, and by their not appearing perfectly *round*."

2. *On the Cassegrainian Telescope.*

The *Cassegrainian Telescope*, which we have represented in Fig. 2. differs in no respects from the *Gregorian*, and had it been brought forward as an improved reflecting telescope, and not as an entirely original invention, its author would have received more credit than has fallen to his share. Montucla,[†] the countryman of the inventor, speaks, we think, too harshly of Cassegrain, unless he had reasons for believing that this author was acquainted with the instruments of Gregory and Newton. Even then, however, he could only be blamed for claiming the priority, while he merited considerable praise for his ingenious substitution of a convex in place of the concave mirror of Gregory. The question of priority is easily settled; for the Gregorian telescope, which it resembles much more than the Newtonian one, was invented before 1661; but the improvement suggested by Cassegrain was truly his own; and though he did not see all its advantages, yet the advantage which he did see, viz. that of shortening the telescope by twice the focal length of the small speculum, was one of no mean import; and when we add to this the correction, to a considerable extent, of the spherical aberration,[*] by the opposite curvatures of the two specula, and the advantages of this instrument first pointed out by Captain Kater, we trust that we shall secure the name of Cassegrain from being spoken of with that disdain which was unworthy both of his own countrymen and of ours.

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[*] When the metals are centered exceeding near, but not accurately true, the true margin of the circle will appear too broad in some one part of its circumference; that is, the black line, forming the circumference of the true circle, will not appear equally broad in every part of it. In such a case, screw up the small screw at the back of the small speculum, which is opposite the part of the circumference of the circle which appears too black, or too broad.

[†] "Lorsque Newton eut publié dans les *Trans. Phil.* son *Nouveau Télescope*, il y eut en France un homme qui pretendit lui en disputer l'invention. M. Cassegrain, c'est le nom de ce rival de Newton, insera dans le *Journal des Savans* de la même année, 1672, diverses pieces tendantes a prouver qu'avant que la recit de l'invention de Newton eut passer la mer, il avoit imaginé un telescope a reflexion, et même superieus a celui du philosophe Anglois."—*Hist. des Math.* tom. ii. p. 540.

It is curious, and at the same time highly instructive, to read the strong objections which Sir Isaac Newton makes to the Gregorian and the Cassagrainian telescope, and to consider how completely the Gregorian telescope was preferred to the Newtonian one during the greater part of the last century. The failure mentioned by Newton, of Mr. Reeves, an English optician, in constructing a six foot Gregorian telescope, under the inspection of its inventor, so early as 1664, arose from the great delicacy required in the adjustment of all its parts; and it appears that Gregory, after a rude trial, was so impressed with the belief that the figure of the mirror was defective, that he never even made a tube to hold the mirrors. Our countryman, therefore, was too precipitate in abandoning his attempts to construct his telescope; and Newton was not less so, when he remarked, "that he could wish that M. Cassegrain had tried his design before he divulged it; but if, for farther satisfaction, he please hereafter to try it, I believe the success will inform him that such projects are of little moment till they be put in practice."[†]

In the Cassegrainian telescope, shown in Fig. 2. the rays RA, coming from the lower end N, of the object MN, and RB coming from its upper extremity M, are reflected, so that they would form an image at F, the focus of the speculum; but being intercepted by the convex speculum S, they are made to converge to foci at $\mu\nu$, and there form an inverted image of the object MN, which may be magnified either by a single eye-glass, or by a Huygenian eye-piece, as already described. Hence it is obvious that the Cassegrainian telescope is shorter than the Gregorian by more than twice the principal focal length of the small speculum S.

From the following table of the dimensions of Cassegrainian telescopes, founded on Dr. Smith's calculations, it appears, that though they are shorter by twice the focal distance of the small speculum than those of the Gregorian form with the same focal length, yet they have a greater magnifying power. A Cassegrainian telescope, 15½ inches in focal length, will magnify, according to the table, 93 times; while a Gregorian one, with a similar speculum, magnifies only 86 times. This great difference between the performance of these instruments does not exist merely in theory; for Mr. Short constructed a telescope of the Cassegrainian form, of 24 inches focus, which, with an aperture of six inches magnified 355 times. With this power, indeed, it was rather indistinct; but it bore a power of 231 times with sufficient distinctness. In the observatory at Greenwich, there is a Gregorian telescope of Short's construction, which magnifies 250 times when the smallest mirror is employed, which is considerably less than the power of the Cassegrainian one of the same size.

Table of the Dimensions, Focal Lengths, and Apertures, of Cassegrainian Telescopes.

Focal length of the great Speculum.	Breadth of the great Speculum.	Breadth of the small Speculum, and of the Hole in the large one.	Focal length of the small Speculum.	Distance between the two Specula.	Distance between the large Speculum and the Plane Surface of the first Eye-glass.	Focal distance of the first Eye glass, or that next the Metals.	Focal. distance of the second Eye-glass, or that next the Eye.	Distance between the Plane Sides of the two Lenses.	Distance between the second Eye-glass and the small Eye-Hole	Diameter of the Diaphragm placed in the anterior Focus of the Lens	Magnifying Power.
Inch. Dec.	Inch. Dec.	Inch Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Inch. Dec.	Times.
15.50	3.52	0.40	1.97	13 51	1.41	3.17	1.06	2,11	0.53	0.18	92.91
36.00	6.57	0.59	3.57	32 75	1.65	4.69	1.56	3.03	0.78	0.26	173.28
60.00	9.61	0.77	3.17	55.21	2 97	6.06	2.02	4.04	1.01	0.34	253.44
1	2	3	4	5	6	7	8	9	10	11	12

In the following table, Dr. Smith has given the focal lengths, the size of the field-bar, and the distances of the eye-glasses of a Huygenian eye-piece, as suited to Cassegrainian telescopes.

Focal length of the great Speculum.	Distance of the Plane Surface of the first Lens behind the Vertex of the great Speculum.	Distance between the Plane surfaces of the two Lenses.	Focal length of first Lens reckoned from the Plane Surface.	Focal length of second Lens reckoned from the Plane Surface.	Distance of the Eye-Hole behind Plane Surface of the second Lens.	Semi-diameter of the Field-bar or Diaphragm.
Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
15.5	6.151	2.396	3.594	1.198	0.598	0.200
15.5	1.415	2.113	3.170	1.057	0.528	0.177
36.00	1.653	3.029	4.694	1.565	0.782	0.262
60.00	2.972	4.037	6.056	2.019	1.010	0.338

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[*] See Wood's *Optics*, p. 211

[†] *Phil. Trans.* 1672, No. 83, p. 4056.

In adjusting and centering the mirrors and lenses, all the operations described by Mr. Edwards must be reversed when applied to the Cassegrainian telescopes.

Although the Cassegrainian telescope appeared, from the excellence of those made by Mr. Short, to be practically, as well as theoretically superior to those of the Greogorian form, yet, from causes which are not very obvious, the Gregorian form was almost universally adopted. During some astronomical observations, however, with the Cassegrainian telescope, Captain Kater was surprised to find it much superior to a Gregorian of the same magnifying power, and immediately undertook a comparison of the two instruments, both of which were made by Mr. Crickmore of Ipswich. Both of the telescopes had nearly the same power, and the specula were made from the same pattern and of the same metal. He then varied the aperture of the Cassegrainian telescope, till he found that both instruments exhibited the letters of a printed card with equal clearness and distinctness. After deducting from the exposed area of each the area of the small speculum and its arm, he found that the reflecting surface of the Cassegrainian telescope was 4.63, while that of the Gregorian was 10.871, making the light of the former to that of the latter nearly as *seven* to *three*. With other instruments he obtained the following results, which are reduced to the same aperture and power.

No. 1.	Gregorian	100	1.	Cassegrainian	235
2.	do.	100	2.	do.	148
3.	do.	100	3.	do.	284

In the second of these comparisons the Cassegrainian speculum was tarnished, which accounts for its inferiority to the rest.

Perceiving that the difference between the performance of the two instruments arose from the rays not having crossed one another at the focus* in the Cassegrainian telescope, Capt. Kater next endeavoured to ascertain the difference of the intensity of the rays at equal distances without and within the focus of a concave speculum, and he obtained the following results:

Intensity of light within the focus	1000	Intensity of light without the focus . .	477.5
do.	1000	do.	431.2
do.	1000	do.	451
do.	1000	do.	448.5
do.	1000	do.	463.7
do.	1000	do.	451.1

The medium of all the observations, some of which were repeated several times, gives the relative intensity of the light *within* and *without* the focus, as 1000 to 449.2, which is considerably more than double.

In another class of experiments, which were made with two lamps of equal sized flames, placed at different distances from the speculum, so that their images were received on cards, one of which was illuminated by the image of the flame *within* the focus, and the other with its image *without* the focus, Captain Kater was enabled to make a simultaneous comparison of both images. The mean of these observations gave the ratio of 1000 to 788, and when the experiment was repeated with pieces of ground glass, the ratio was 1000 to 655. These results are so very different from the preceding, that some new experiments made with homogeneous light are essentially necessary to establish the fact of a great difference in the intensity of the rays within and without the focus. For farther information on the Cassegrainian telescope, see the *Journal des Savans*, 1672, p. 80. 121; *Phil. Trans.* No. 83, p. 4056, 1672; Montucla, *Hist. des Math.* tom. ii. p. 540; Smith's *Optics*, tom. ii Rem. p. 105; Ferguson's *Lectures*, vol. ii. *Appendix*. *Phil. Trans.* 1813, part. ii.; 1814, part i.; and Dr. Brewster's *Treatise on New Phil. Inst.* p. 44. 193.

3. *On the Newtonian Telescope.*

The *Newtonian* telescope, which derives its name from its illustrious and undoubted inventor, can be considered in no other light than as an improvement, or rather a change, upon the Gregorian telescope, which was distinctly described in 1663, in the *Optica Promota.* Although Newton himself states, that he was acquainted with the *Optica Promota* before he had invented his reflecting telescope, which was decidedly not till after 1664, and probably not till 1666; yet it strikes us with surprise, that he did not mention the telescope of Gregory till he was called upon to make some remarks upon the analogous contrivance of Cassegrain.† Nay, he does not even mention the name of Gregory in his account of reflecting telescopes, in the Treatise on Optics, so that a reader cannot fail to draw the conclusion, that Newton was the only person that had wrote on that subject.

In a letter to a friend, dated February 23, 1668–9, Sir Isaac gives an account of "a small prospective," made to try the truth of his conjecture respecting reflecting telescopes. It was $6\frac{1}{4}$ inches long, had an aperture about an inch and a third, a plano-convex eye-glass 1·6th or 1-7th of an inch deep, and magnified about thirty-five times, which he considered as more than could be done by a six feet refracting telescope. With this instrument he saw the horns of Venus, and the Satellites of Jupiter; but, not content with such an experiment, he completed another speculum $2\frac{1}{3}$ inches broad, and satisfied himself completely of the superiority of these instruments, which were afterwards brought to such perfection by the labours of Mr. Hadley and Sir W. Herschel.

The *Newtonian telescope* is represented in Fig. 3. where AB is a parabolic speculum, placed at the end of a tube ABCD. Rays RA, RB, proceeding from a distant object MN, will be made to converge to foci at F, and will there form a distinct and inverted image of the object, as already explained. But if we interpose a small plane speculum EF, whose distance from the focus F is a little less than its distance from the side of the tube E, and whose inclination to the axis of the tube is 45°, it will form an image $\mu\nu$, a little within the edge of the tube, and parallel to its axis. An eye-glass E is then placed so as to have this image in its anterior focus, and, consequently, the observer will perceive a magnified representation of the object.

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* Captain Kater quotes a remark of Dr. Brewster, who observed the same effect in the best achromatic telescopes, and who mentions it "as a curious fact, that the circular images, or the sections of the cone of rays, are never so distinct and well defined *after the rays have crossed as before.*" See *Treatise on New Phil. Inst.* p. 44. 193; *Phil. Trans.* 1813 and 1814; *Edin. Review*, vol. xxiv. p. 35, and our article GREGORY.

† See *Phil. Trans.* 1672, No. 83, p. 4056.

In order to obtain a reflexion with less loss of light, Sir Isaac Newton proposed to substitute a rectangular prism in place of the small mirror, having its sides perpendicular to the incident and the emergent rays, so that the light may suffer total reflexion from its posterior surface. By making these two faces of the prism convex, "that the rays may cross as well before they come at it, as afterwards, between it and the eye-glass," the object will be seen erect instead of inverted.

As the small plane speculum has an oblique position to the eye, it must be of an elliptical form. In order to find its conjugate or shortest diameter, say as the focal length of the great speculum is to its aperture, so is the distance of the small speculum from the focus of the great one to the conjugate diameter of the small mirror; that is, the conjugate diameter of the small mirror is $=\frac{EF \times AB}{AF}$. Its transverse or longest diameter will be $=\frac{EF \times AB}{AF} \times 1.4142$; that is, equal to the conjugate diameter multiplied by 1.4142; or, which is the same thing, its transverse will be to its conjugate diameter as 7 to 5, which is nearly the ratio of the diagonal of a square to one of its sides. As there is no necessity that the deviation produced by the small speculum should be a right angle, Dr. Brewster has proposed to incline the small speculum from 60° to 80° to the axis of the telescope, and thus throw the image to a side, as in Fig. 4. By this means the quantity of reflected light will be increased, and the imperfections in the surface of the speculum will be diminished. The speculum will thus require to be longer in one direction, but it will not intercept any more of the incident rays.

The only table, containing the apertures, magnifying power, &c. of Newtonian telescopes, which has hitherto been published, was calculated by Dr. Smith,[*] from the middle aperture and power of Hadley's excellent Newtonian telescope, as a standard, the focal length of the great speculum being 5 feet 2½ inches, its aperture 5 inches, and power 208. A speculum, however, 3 feet and 3 inches in focal length, was wrought by Mr. Hauksbee to so great perfection, as to magnify 226 times.[†] It showed the minute parts of the new moon very distinctly, as well as the belts of Jupiter, and the black list or division of Saturn's ring. For these objects, it bore an aperture of 3¼ or 4 inches; but in cloudy weather it showed land objects most distinct, when the whole surface of the metal was exposed, which was 4½ inches in diameter. Since the method of grinding specula, and giving them a true parabolic figure, is much better understood at present than it was in the time of Mr. Hauksbee, Newtonian telescopes may be made as perfect as this instrument of his construction. Upon it, as a standard, therefore, we have computed the following new table, on the supposition that reflecting telescopes of different lengths show objects equally bright and distinct, when their linear apertures, and their linear amplifications, or magnifying powers, are as the *square roots*, or *biquadratic roots*, of the cubes of their focal lengths; and consequently, when the focal distances of their eye-glasses are as the square roots of their lengths.

The first column contains the focal length of the great speculum in feet, and the second its linear aperture in inches, and 100ths of an inch. The third and fourth columns contain Sir Isaac Newton's numbers, by means of which the apertures of any kind of reflecting telescope may be readily computed.[‡] The fifth column exhibits the focal length of the eye-glasses in 1000ths of an inch; and the sixth contains the magnifying power of the instrument.

Table *of the Apertures and Magnifying Powers of Newtonian Telescopes.*

Focal length of the concave speculum.	Apertore of the concave speculum.	Sir Isaac Newton's Numbers:		Focal Length of the Eye-glass.	Magnifying Power.
Feet.	Inch. Dec.	Aperture of the speculum.	Focal length of the Eye-glass.	Inch. Dec.	Times.
½	1.34	100	100	0.107	56
1	2.23	168	119	0.129	93
2	3.79	283	141	0.152	158
3	5.14	383	157	0.168	214
4	6.36	476	168	0.181	265
5	7.51	562	178	0.192	313
6	8.64	645	186	0.200	360
7	9.67			0.209	403
8	10.44	800	200	0.218	445
9	11.69			0.222	487
10	12.65	946	212	0.228	527
11	13.58			0.233	566
12	14.50	1084	221	0.238	604
13	15.41			0.243	642
14	16.25			0.248	677
15	17.11			0.252	713
16	17.98	1345	238	0.256	749
17	18.82			0.260	784
18	19.63			0.264	818
19	20.45			0.268	852
20	21.24	1591	251	0.271	885
21	22.06			0.274	919
22	22.85			0.277	952
23	23.62			0.280	984
24	24.41	1824	263	0.283	1017

As it is more difficult to find any of the heavenly bodies with a Newtonian than with a Gregorian telescope, it has been customary to fix a small astronomical telescope on the tube of the former, so that the axis of the two instruments may be parallel. The aperture of the object-glass is large, and cross hairs are fixed in the focus of the eye-glass. The object is then found by this small telescope, which is called the *finder;* and if the axis of the instruments are rightly adjusted, it will be seen also in the field of the large telescope. When the Newtonian telescope, however, is large, and placed upon its lower end to view bodies in great altitudes, the finder can be of no use, from the difficulty of getting the eye to the eye-piece. On this account, Dr. Brewster proposed to bend the tube of the finder to a right angle, and place a plane mirror at the angular point, so as to throw the image to one side, or rather above the upper part of the tube, that the eye-piece of the finder may be as near as possible to the eye-piece of the telescope. If the latter of these plans be adopted, the angular point, where the plane mirror is fixed, should be placed as near as possible to the focal image, in order that only a small part of the finder may stand above the tube; for in this way the eye can be transferred with the greatest facility from the one eye-piece to the other. The advantages of this construction will be understood from Fig. 5. where G is the eye-piece, and *a b c* the finder. The image formed by the object-glass *a* is reflected upwards by the plane mirror *b*, placed at an angle of 45 degrees with the axis of the tube, and the image is viewed by the eye-glass at *c*. Those who have been in the habit of using the Newtonian telescope with the common finder, will be sensible of the convenience resulting from this contrivance.

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[*] *Optics*, vol. i. p. 148. Dr. Smith's table was continued from 17 to 24 feet, by Mr. Edwards.

[†] Smith's *Optics*, vol. ii. *Remarks*, p. 79, col 2.

[‡] See David Gregory's *Optics*, Appendix, p. 229; and the *Philosophical Transactions*, No. 81, p. 4004.

4. *Account of Sir W. Herschel's Large Telescope.*

The Newtonian telescopes, which had for a long time been thrown into the shade by the fine Gregorian ones constructed by Mr. Short, were revived, towards the end of the last century, by Sir W. Herschel, as we have already stated in our history of the science. His telescope of forty feet will long remain a splendid example of royal munificence, and of the zeal and ingenuity of its inventor. We have endeavoured to give a representation of this noble instrument in Plate CCCCXLI. and shall now attempt to convey an idea of its construction. The drawing of this telescope represents it in a meridian situation, when seen at a convenient distance by a person placed to the south-west of it. It rests on a foundation of two concentric circular brick walls, the outermost of which is forty-two feet in diameter, and the innermost twenty-one feet. These walls are two feet six inches deep under ground; two feet three inches broad at the bottom, and one foot two inches at the top, and they are capped with paving stones, about twelve and three-fourth inches broad, and about three inches thick. Upon these two walls, which were made uniform on the surface, and horizontal, with the greatest care, rests the bottom frame of the whole apparatus, which moves upon twenty concentric rollers, and is always moveable upon a pivot, which gives a horizontal motion to the whole apparatus. The length of the ladders is forty-nine feet two inches, and the flats and rounds are all made of solid English split oak. The two outside divisions of the ladders serve for mounting into the gallery. The middle top cross beam rests on the angle made by the crossing of the two sets of ladders. There is a small staircase, by which we may ascend into the gallery without being obliged to go up the ladders, and as the gallery is strong enough to hold a company of several persons, and can afterwards be drawn up to any altitude, observations may be made with the greatest facility and conveniency.

The great tube, though of a very simple form, was constructed with much difficulty. It is thirty-nine feet four inches long, four feet ten inches in diameter, and every part of it is made of rolled or sheet iron, joined together without rivets, by a kind of sealing used in the manufacture of iron funnels for stoves. The whole outside was thus put together in all its length and breadth, so as to make one sheet of nearly forty feet long, and fifteen feet four inches broad. Each sheet of iron was three feet ten inches long, and about 23½ inches broad. Their thickness was less than the 36th part of an inch, and a square foot weighed about fourteen ounces. Had the tube been made of wood, its weight would have exceeded that of the iron one at least 3000 lbs.

The metal of the great mirror is 49½ inches in diameter, but on the rim there is an offset of three-fourths of an inch broad, and one inch deep, which reduces the concave face of it to a diameter of 48 inches of polished surface. The thickness, which is uniform throughout, is about 3½ inches, and its weight, when newly cast, was 2118 lbs. of which it must have lost a small quantity in polishing. In order to preserve the speculum from damp, a flat cover of tin was soldered on a rim of iron, about 1¾th inches broad and ⅛th thick, the diameter of which is equal to that of the iron ring which holds the speculum. On the flat part of the rim, some close-grained cloth, of an equal breath with the rim, is cemented all round, so that the rim of the cover, when put over the speculum, fits closely to the edge of the iron ring.

The method of observing with this telescope, is what Sir William Herschel calls the front view, and for this purpose there is a convenient seat S fixed to the end of the tube, in which the observer sits with his back towards the object he views. The seat is moveable from the height of one foot seven inches to two feet seven inches, partly for the accommodation of different observers, but chiefly for the alteration required at different altitudes. This seat is brought to a horizontal position by turning a handle attached to a bar, carrying two pinions, which work in two strong toothed quadrants of iron Q at the sides of the seat. The focus of the great speculum is brought down by its proper adjustment to within four inches of the lower side of the mouth of the tube, and comes forward into the air, and by this arrangement there is room for that part of the head which is above the eye, not to interfere greatly with the rays that pass from the object to the mirror; the aperture of the speculum being four feet, while the diameter of the tube is four feet ten inches.

A slider on an adjustable foundation is fixed at the mouth of the telescope, so as to be directed to the centre of the speculum. It carries a brass tube, into which all the single eye-glasses are made to slide. When they are nearly brought to the focus, a milled head under the end of the tube, turns a bar, the motion of which adjusts them completely, so that as there is no small speculum, the eye-glasses are applied immediately to magnify the inverted image in the focus of the great speculum.

From the mouth of the telescope a speaking pipe descends to the bottom of the tube, when it divides into two branches, one of which enables the observer to communicate with his assistant in the observatory D, and the other with the workman in the room E, who gives the instrument all its movements.

A sidereal time-piece is placed in the observatory, and close to it a polar distance-piece, which may be made to show polar distances, declination, or altitude, by setting it differently. The time and polar distance-pieces are placed in such a manner, that the assistants sit before them at a table, the speaking pipe rising between them, and in this manner observations may be very conveniently made.

This splendid instrument magnifies above 6000 times, and Sir William has sometimes employed a power of 6450 for the fixed stars. These high powers are obtained merely by using small double convex lenses for eye-glasses. Some of these, ground and polished with the utmost care, are so small as *one-fiftieth of an inch* in focal length. The existance of such minute lenses we should have thought incredible, had we not possessed them as made by the same ingenious artist, (the late Mr. Shuttleworth,) who ground them for Sir William Herschel.

5. *New Telescope proposed by Burckhardt.*

In the *Connaissance des Tems* for 1809, M. Burckhardt has described a new telescope of a nature intermediate between the Newtonian and Gregorian form, and requiring a tube only half as long as other instruments of the same focal length. In this instrument, a plane speculum *p q*, supported by a bar *s t*, is placed *half way* between the mirror AB and its principal focus, so as to intercept the cone of rays, and reflect them to a focus at H, within the perforation of the speculum, where they are viewed by the lens C. M. Burckhardt proposes another form also, if we rightly recollect, to use a mirror without an aperture, like the Newtonian one, and to incline the small speculum *p q*, so as to throw the image immediately above A, where it is viewed by the eye-lens[*] The only advantage of the *first* of these constructions is, to diminish the length of the telescope nearly one-half; while it has the very great disadvantage of requiring a large plane mirror *p q*, which it is not only very difficult to grind truly flat, but which obstructs a larger portion of light that would have fallen on the central parts of the speculum. In the Newtonian telescope, too, the rays are reflected by the small speculum at an angle of 45°, and therefore more copiously than at a perpendicular incidence, as in the preceding combination.

The Board of Longitude of France seem not only to have had a favourable opinion of the preceding instrument, but also to have thought the contrivance an original one; for they ordered, at their own expense, a telescope to be constructed on the principle recommended by M. Burckhardt. The idea, however, is nearly as old as the Gregorian telescope; and it is singular that such a learned body should not have known, that it is described by James Gregory himself, in a letter to Mr. John Collins, dated Sept. 26th, 1672, which is published in David Gregory's *Elements of Catoptrics and Dioptrics*. (2d edit. p. 261, 262.) Sir Isaac Newton having, as we have previously remarked, pointed out the disadvantages of the Cassegranian telescope, Mr. James Gregory, considering the Cassegranian telescope as the same with his own, "thought himself obliged to answer to the disadvantages Mr. Newton finds in it." and he then observes, "I mak, therfor, *p q* an plane speculum, and then almost the whol disadvantages evanishe, except onlie the third; and for that ther is an advantage as considerable, if not more, viz. that the distance HF (Fig. 1.) groweth almost the one-half lesse; and therfor the errors of the concave AB ar also diminished upon the plane *p q* by one-halfe. Ther is yet another advantage of this telescope, that it will be *little more than halfe the length of Mr. Newton's*, and doe the same effect. * * * *. This telescope *with the plane speculum* will indeed lose maire of the best raies; but these nevertheless are always less than one-fourth of the whole, the eye-glass being advantageously situate; which defect some perchance may think recompensed by the shortness of the telescope." See the *Connaissance des Tems* for 1809. *Philosophical Magazine*, 1809, vol. xxxiii. p. 290; and David Gregory's *Elements of Catoptics and Dioptrics*, 2d edit. p. 261—264.

6. *New Reflecting Telescope proposed by Dr. Brewster.*

We believe it will be universally admitted by every person who has had much experience in the construction and use of reflecting telescopes, that the Newtonian form is decidedly the best. Its construction is so simple, and it is so little liable to derangement from accidental causes, that for popular use, on a small scale, it is superior to the Gregorian one, while, for instruments of great size, it is the only form that is practicable. But even when we consider it in a scientific point of view, it has the advantage of the Gregorian form. It is more easy to give a perfect figure to an uniform circular piece of metal than to a perforated disc;—the spherical aberration is less, in so far as it is not increased by a second spherical mirror;—and the quantity of light reflected from the oblique small speculum is decidedly greater than when it is reflected at a vertical incidence.

If we could dispense with the use of the small specula in telescopes of moderate length, by inclining the great speculum, and using an oblique, and consequently a distorted reflexion, as proposed first by Le Maire, we should consider the Newtonian telescope as perfect; and on a large scale, or when the instrument exceeds twenty feet, it has undoubtedly this character, as nothing can be more simple than to magnify by a single eye-glass the image formed by a single speculum.

As the *front view* is quite impracticable, and indeed has never been attempted in instruments of a small size, it becomes of great practical consequence to remove as much as possible the evils which arise from the use of a small speculum. These evils may be thus enumerated:

1. If we suppose the light reflected by the large speculum to amount to 10,000 rays, then the light reflected by a well polished plane speculum will not exceed one-third, or 6666 at a vertical incidence, and probably not above 6800 at an incidence of 45°;[†] consequently 3100 rays out of 10,000 are lost by the use of the plane speculum.

2. Besides this great loss of light, we have to encounter all the errors of a second reflexion, arising from imperfection of figure, and also from imperfections of surface, as it is universally admitted that a surface of glass is much superior to a metallic surface; and Newton has himself remarked, "that every irregularity in a reflecting superficies makes the rays stray *five or six times* more out of their due course than the like irregularities in a refracting one."[‡]

The construction by which Dr. Brewster proposes to remedy these disadvantages is shown in Fig. 4. where AB is the speculum, reflecting the parallel rays RA, RB, to a focus at F. The cone of rays AFB is intercepted by an achromatic prism GH, which refracts them to foci at *f*, where a distinct image is formed in the anterior focus of the eye-glass E, by which it is magnified. The compound prism GH being composed of a prism of crown glass, and a prism of flint glass H, united by a cement of a mean refractive power, the loss of light sustained by the pencil, in its transmission through the two, will not exceed 600 rays out of the 10,000, as the light transmitted through a lens of glass is 9485 out of the 10,000 incident rays. Hence the light lost by transmission through the prism is not *one fifth* part of the light lost by reflexion; and the errors of reflexion arising from defect of surface and of figure are also incomparably less. As the refracting angle of the prism G will require to be larger, in order to produce a given deviation FH*f*, when it is opposed by the refraction of the flint glass prism H, we may place the correcting prism H nearer the focus *f*, as shown in Fig. 5, and make it of crown glass; or it might even be placed at *h*, beyond the focus, and in contact with the lens E. If this should be found advantageous, the prism and the lens might be formed out of one piece of glass, or a single hemisphere of glass might be used, the eye-hole being placed at such a point of the hemispherical surface, as to obtain a variable prism of the required angle united with a plano-convex lens.*

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[*] Telescopes upon this principle were not only made, but advertised for sale, more than six years before the date of M. Burckhardt's paper, by Mr. Paterson, who had then the charge of the observatory of Edinburgh. We fitted up a telescope in this manner, in imitation of Mr. Paterson; but the result of the experiment was by no means favourable.

[†] The law of variation is yet undetermined.

[‡] The deviation of a ray arising from the imperfections of a reflecting surface, is to the deviation arising from the imperfections of a refracting surface, as *four* to *one*, when the refraction is made from glass into air, and as *six* to *one*, when the refraction is made from air to glass.

As Dr. Maskelyne found that the Greenwich Newtonian telescope was greatly improved by inclining the speculum, or its axis, about 2½° to the axis of the tube, it follows, that it performed best with oblique pencils in a certain direction. Before fitting up this telescope, therefore, or indeed any Newtonian telescope, it should be ascertained, by turning the speculum in its cell, and giving its axis various degrees of obliquity, whether or not its performance is improved. If this is found to be the case, and that the angle of inclination is 2½°, we shall then require a less angle in the prism G, as part of the deviation of the pencil to the side of the tube is already produced by the new position of the axis of the speculum.

It is obvious that any rays incident on the prism GH, parallel to the tube, will be refracted upon the side of the tube, and will have no effect upon the image; but if they should be thought injurious, we have only to place an opaque screen, of the same size as GH and its arm, somewhere between GH and the mouth of the tube, so as not to interfere with the cone of refracted rays GH*f*.

This form of the reflecting telescope enables us to construct a very simple double image micrometer, the prism H, either when united with G, as in Fig. 3. or when separated, as in Fig. 5. being made of a doubly refracting crystal, cut in such a manner as both to correct the colour of G, and produce the two images.

In viewing eclipses of the sun, or the lunar disc, or any other celestial phenomenon, where there is either too much light, or more than is necessary, a telescope may be fitted up to permit more than one person to see through it at the same time, by allowing a portion of the cone of rays to be refracted through another prism to an eye-glass at the opposite side of the tube, or even by having four prisms refracting a fourth part of the cone to each of the four sides of the tube. The same effect might be produced in the common Newtonian telescope, by using a pyramidal small speculum with the planes meeting at a vertex placed in the centre of the cone of rays, and inclined to one another at angles of 90°, and to the axis of the telescope at angles of 45°.

Art. III.—*On the Cause of the Tremors of Reflecting Telescopes, and the Method of Removing them.*

In using reflecting telescopes of high magnifying powers, every person must have been struck with the imperfection of vision arising from the tremors with which they are affected. During Dr. Maskelyne's long experience, he always found that the reflecting telescopes at Greenwich, viz. a Gregorian of two feet and a Newtonian of six feet, showed the celestial objects indistinct, and affected with tremors, when the 46 inch triple achromatic telescope showed them almost entirely free of them, and generally more distinct and better than even the six feet reflector. He observed the same effect in viewing land objects. The effect of tremors, indeed, in producing indistinct vision, was so great, that Dr. Maskelyne had been long of opinion, "that reflecting telescopes ought to be banished from astronomical uses." Upon requesting the Rev. Mr. Edwards, however, to investigate the cause of this great defect, that ingenious individual undertook the task, and completely succeeded, not only in detecting the cause of these tremors, but in discovering a remedy for them. These causes were the springs which were employed to press the telescope into its cell, and the small eye-hole which was always used in reflectors. By removing, therefore, the springs at the back of the great speculum, and supporting the speculum on two pieces of card, wedged into its cell, about 45° on each side of its lowest point, and by taking away entirely the eye-hole in the Greenwich Newtonian reflector, Dr. Maskelyne found it so much improved, as to show a printed paper sensibly better and more distinct than the 46 inch achromatic telescope, which was formerly so superior to it.†

When the specula of reflectors are made to rest on their lowest point, the weight of the metal bends the speculum in a small degree, and injures its figure. "This," says Mr. Edwards, "may appear strange; but I can at any time totally spoil the figure of a metal by wedging it in only with the thickness of a bit of common writing paper. Dr. Smith says, *one thousandth* of an inch will spoil its figure. I am sure, also, that that quantity, if not less, will injure it."

From this observation, we think it quite evident, that if the speculum of a moderate size was bent by resting on its lower point, a speculum of a larger size must also be bent when supported at the two points above mentioned. We would therefore strongly recommend to the artist not to allow the edge of his specula to rest on any point at all, but to fix them by their back either to a plate of brass, or a frame, so as to be suspended, as it were, by every part of their posterior surface. See Edwards's *Directions for Making the best Composition for Reflecting Telescopes*, in the *Nautical Almanack* for 1787.

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* Every plano-convex lens, or plano-concave lens, may be converted into a lens and a prism combined, by shifting the eye-hole from the vertex of the lens to one side.

† Dr. Maskelyne found that good reflecting telescopes, such as those made by Mr. Edwards, "show objects as bright as a treble object-glass achromatic telescope, both being put under equal circumstances of areas, and the aperture of the object-metal and object-glass, and equal magnifying powers, whereas the diameter of the aperture of a common reflecting telescope must be to that of the achromatic telescope as 8 to 5 to produce an equal effect."

ART. IV.—*On the Achromatic Telescope.*

Having already, in our article on ACHROMATIC TELESCOPES, and in our chapter on Chromatics in this article, given a full account of the principle of the achromatic telescope, and very full details respecting the radii of curvature for the different lenses, we shall not enter into any farther theoretical details on the subject.

The principle of achromatic combinations is demonstrated in Prop. XI. p. 675, and all that is at present known respecting the secondary spectra, and the dispersive actions of various bodies, has been fully detailed in the subsequent propositions. We shall therefore content ourselves with laying before our readers an account of the recent valuable investigations of Mr. Herschel, of which we are enabled to give a practical and popular abstract, as contained in a letter from that distinguished philosopher, addressed to Dr. Brewster, and printed in the *Edin. Phil. Journal*, vol. vi. p. 361.

1. *Practical Directions for constructing Double Achromatic Object-Glasses of Crown and Flint Glass.*

The first thing essentially requisite for an artist who would construct a refracting telescope by regular rules, by any certain process, independent of trials, is to know the materials he has to work upon. The refractive and dispersive powers of the glass employed, or at least the proportion of the latter, are indispensable data, and must be obtained before any calculation from theory can be made. The former is easily obtained, by grinding a small portion of the glass into a prism or lens, and observing the deviation of the most luminous rays, or the best focus of the lens; but the latter, I am sorry to say, is an element whose determination presents great difficulties, at least when required to a degree of exactness such as the purposes of the achromatic telescope demand. In fact, the achromaticity of a double object-glass is itself so delicate a test of the adjustment of the dispersive powers of the lenses, that we cannot expect to succeed to the required degree of nicety in ascertaining their ratio in any instance, without employing a mode of observation at least as delicate. However, as this difficulty bears equally upon every construction of the telescope ever yet proposed, and as the best artists do actually, previous to working their glasses, make some estimate of the ratio of the dispersive powers, on which to ground a calculation of the radii, sufficient for their own satisfaction, I may assume, for the present, that a knowledge of the dispersive, as well as the refractive powers of the media, may be obtained, remarking only, that when an optician has the good fortune to meet with a parcel of glass from one melting-pot, sufficiently pure for his purposes, it is well worth his while to bestow the utmost pains on the accurate determination of this most important point. This will require the sacrifice of no portion of his glass capable of being used for large lenses, as neither the refractive nor dispersive powers of specimens made at one casting, can be supposed liable to such variations as materially to affect his results. A fragment cut from the corner of one of his plates will suffice, if properly used, for all his wants.

The imperfections to which refracting telescopes are chiefly liable, are well known to originate in two sources,—the want of proportionality in the dispersive actions of glasses of different kinds on the differently coloured rays, and the spherical figure of the lenses. The former of these imperfections is demonstrably insuperable in the ordinary case of a double object-glass, where only flint and crown glass are used. The best we can do is, to work the lenses so as to produce the same compound focus, not for all the rays, for that is impossible, but for the two brightest and strongest colours in decided contrast with each other.

From some experiments on the colours developed by crystals in polarised light,* I am induced to conclude, that the colours we ought to take pains to unite, in order to produce the whitest possible pencil, are the brighter red, bordering on orange, and that part of the spectrum where the blue is most vivid, and begins to pass into green. Supposing these rays perfectly united, all the rest will be nearly so, and the two extremities of the spectrum will both deviate one way from the exact focus, while the intermediate portion will deviate the other, thus producing the phenomenon always observed in well adjusted achromatic telescopes when thrown out of focus, viz. a purple or lilac fringe surrounding the image of a white object on one side of the focus, and a green on the other. This is the criterion of a good adjustment of the foci; and to go beyond this point, with the ordinary materials, seems hopeless. I would recommend, then, to the optician who has been fortunate enough to procure fine specimens of glass, on the working of which he thinks it worth while to bestow much pains, (especially if he should have enough for several object-glasses,) to determine the ratio of the dispersive powers of his flint and crown glasses, by a direct experiment on small portions of his materials, working them into a small object-glass, having the ratio of the focal lengths of its component lenses, as nearly as he can guess, in the proportion of their dispersions, but leaving rather a preponderance on the side of the crown or convex lens, and then by degrees reducing the curvature of one of the surfaces of this, till he obtains the nearest possible approach to perfect achromaticity, *i. e.* till the purple and green fringes surrounding a white object on a black ground, appear in it as above described, when thrown one way or the other out of focus. (using a pretty strong magnifier.) Let him then determine accurately, *by experiment*, the focal length of each of his two lenses, and dividing the one by the other, he will obtain a *dispersive ratio* (ratio of the dispersive powers) on which he may calculate *with perfect security* in his future operations. If he know the exact radii of his tools, he may at the same time determine the refracting powers of the media.

These data once obtained, we are prepared to determine from theory the radii of the several surfaces which, in a telescope of given focal length, shall destroy that imperfection which arises from the spherical figure. This problem is well known to be of the kind called indeterminate, or admitting an infinite variety of solutions. In consequence, an unlimited variety of combinations of lenses, free from spherical aberration, may be discovered; and to fix our choice among them is a matter of considerable delicacy, as well as importance. Various constructions have been proposed by different writers. Thus D'Alembert has given one, in which he destroys the spherical aberration, not merely for rays of mean refrangibility, but for those of all colours; but this, however refined in theory, is quite useless in practice, as is also another construction investigated by the same author, in which the aberration of rays diverging from a point of the axis is annihilated, and the field (so far as the object-glass is concerned) rendered equally perfect in every point. Such refinements must be regarded as merely visionary, correcting inconveniences which have never been felt in practice, and leaving unsatisfied other more essential conditions. A much better construction was devised by Clairaut, in which the two internal surfaces are worked to equal radii, the one convex, the other concave, so as to admit of the two glasses being cemented together, and thus avoid the loss of light, by reflexion at two surfaces. Clairaut, however, has employed in his computations indices of refraction (1.600 and 1.55) higher, especially the latter, than what are now easily met with; and when the average values, those likely to occur most frequently, are employed, the construction becomes imaginary for the more dispersive kinds of glass; and within the limits for which it is real, the radii change so rapidly, as to render it difficult to interpolate between their calculated values; so that this construction loses much of its real advantage to the artist who is no algebraist.

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* *Phil. Trans.* 1820, i. p. 98.

In the construction proposed in my paper, the destruction of the spherical aberration is insured, not only for parallel rays, but also for those which diverge from objects placed at any moderate finite distance, so as to produce a telescope equally perfect for terrestrial and astronomical purposes. This is the condition introduced to render the problem determinate; but the advantage afforded by it would not alone be such as to induce us to adopt it, in preference to many others which might be devised, were it not that the radii resulting from it are such as to satisfy other and much more important practical conditions, which may be shortly stated as follows:

1*st*, The curvatures assigned in this construction to all the surfaces are moderate; more so, indeed, than in any other hitherto proposed on true theoretical grounds, for an aplanatic object-glass.

2*dly*, In this construction, the curvatures of the two exterior surfaces of the compound lens, of given focal length, vary within extremely narrow limits, by any variation in either the refractive or dispersive powers, at all likely to occur in practice. This remarkable circumstance affords a simple practical rule, applicable in all ordinary cases, for calculating the curvatures in any proposed state of the data, and requiring only the use of theorems with which every artist must be familiar, and, at all events, rendering it extremely easy to interpolate between calculated values. I have shown in my paper, that *a double object-glass will be nearly free from aberration, provided the radius of the exterior surface of the crown lens be* 6.72, *and of the flint* 14.2; *the focal length of the combination being* 10.00, *and the radii of the interior surfaces being computed from these data, by the formulæ given in all elementary works on optics, so as to make the focal lengths of the two glasses in the direct ratio of their dispersive powers.*

In this construction, the anterior glass, or that which first receives the incident rays, is crown, and is double convex, of unequal convexities; the flatter surface being placed outwards, while the posterior lens, formed of flint-glass, is concavo-convex, having its concave surface applied against the posterior or most convex surface of the crown lens. This combination is represented in Fig. 6. where the four surfaces are numbered in the order in which the light traverses them, O being the object, and F the image formed in the focus.

The rule here stated is given only as approximative, but will no doubt be sufficiently exact for ordinary use; but when object-glasses of great size and value are to be constructed, their radii must be computed more strictly; and for this purpose I have subjoined a table, calculated upon the rigorous formulæ, the construction and employment of which will be explained presently.

3*dly*, Another practical advantage afforded by this construction is, that the two interior surfaces approach in all cases so near to coincidence, that no sensible error can arise from neglecting their difference, and figuring them on tools of equal radii. Indeed, for a dispersive ratio a little above the average, they would coincide rigorously, and this construction would be identical with that of Clairaut above mentioned; and so nearly is this approach to equality sustained throughout the whole extent of the variations in the data, that even when the dispersive ratio is so low as 0.75 : 1, (a case almost useless to consider,) the difference amounts to less than one-fortieth part of the curvature of each.

Table, containing the Dimensions of an Aplanatic Double Object-Glass.

Refractive Index of Crown Lens, - 1.524 } Compound Focal Length, 10.000.
Refractive Index of Flint Lens, - 1.585 }

Dispersive ratio.	1st Surface, Convex.			2d Surface, Convex.	3d Surface, Concave.	4th Surface, Convex.			Focal Length of the Crown Lens.	Focal Length of the Flint Lens.
	Radius for the above Refractive Indices.	Variation of Radius for a change of + 0.010 in Ref. index of Crown Glass.	Variation of Radius for a change of + 0.010 in Ref. index of Flint Glass.	Radius.	Radius.	Radius for the above Refractive Indices.	Variation of Radius for a change of + 0.010 in Ref. index of Crown Glass.	Variation of Radius for a change of + 0.010 in Ref. index of Flint Glass.		
0.50	6.7485	+0.0500	—0.003	4.2827	4.1575	14.3697	+0.9921	—0.3962	4.0	10.0000
0.55	6.7184	+0.0740	—0.0011	3.6332	3.6006	14.5353	+1.0080	—0.5033	4.5	8.1818
0.60	6.7069	+0.0676	+0.0037	3.0488	3.0640	14.2937	+1.1049	—0.5659	.0	6.6667
0.65	6.7316	+0.0563	+0.0125	2.5208	2.5566	13.5709	+1.1614	—0.6323	3.5	5.3846
0.70	6.8279	+0.0335	+0.0312	2.0422	2.0831	12.3154	+1.1613	—0.7570	3.0	4.2858
0.75	7.0816	—0.0174	+0.0568	1.6073	1.6450	10.5186	+1.0847	—0.7207	2.5	3.3333

The dimensions in the above Table are computed on the supposition of the focal length of the object-glass being 10; and to adjust them to any other assigned focal length, all that is required is, to increase or diminish the radii here set down, in the proportion of the assigned focal length (in inches, feet, or parts of any given scale) to 10 parts of the same scale.

When the refractive powers of the two media are exactly 1 524 and 1.585 (which are nearly their average values) respectively, and the dispersive ratio is any one of the numbers in the first column, this table gives at once the exact values of the radii required; but when this is not the case, we must proceed as follows:

Suppose, for example's sake, we would find the proper radii for the surface of an object-glass of 30 inches focal length, the refractive index of the crown lens being 1.519, and that of the flint 1.589, the dispersive power of the former being to that of the latter as 0.567 : 1, or .0567, being the dispersive ratio.

The computation must first be made as for an object-glass of 10 inches focus; and first we must determine the focal lengths of the separate lenses. To this end,

1. Subtract the decimal (0.567) representing the dispersive ratio from 1.000; and the remainder, multiplied by 10, is the focal length of the crown lens, (in this case 10 × 0.433, or 4.330.)

2. Divide unity by the decimal above mentioned, (0.567,) subtract 1.000 from the quotient, and multiply the remainder by 10, and we get the focal length of the flint lens. In the case before us, $\frac{1}{0.567} = 1.7635$, and $0.7635 \times 10 = 7.635$ is the focal length required.

We must next determine, by the Tables, the radii of the 1st and 4th surfaces for the dispersive ratios there set down (0.55 and 0.60,) next less, and next greater than the given one. For this purpose we have

Refractive powers given, . . .	1.519	and 1.589
Refractive powers in the Table, .	1.524	1.585
Differences,	—0.005	+0.004

the given refraction of the crown being less, and the flint greater, than their average values on which the Table is founded. Looking out now opposite to 0.55 in the first column for the variations in the two radii corresponding to a change of + 0.010 in each of the two refractions, we find as follows:

	1st Surface.	*4th Surface.*
For a change = +0.010 in the Crown,	+0.0740	+ 1.0080
For a change = +0.010 in the Flint,	—0.0011	— 0.5033

But the actual variation in the crown, instead of + 0.010, being — 0.005, and in the flint, instead of + 0.010 being + 0.004, we must take the proportional parts of these, changing the sign in the case of the crown. Thus, we find the variations of the first and last radii to be,

	1st Surface.	*4th Surface.*
For —0.005 variation in the Crown,	— 0.0370	— 0.5040
For +0.004 variation in the Flint,	— 0.0004	— 0.2013
Total variation from both causes,	— 0.0374	— 0.7053
But the radii given in the Table are,	+ 6.7184	+ 14.5353
Hence radii interpolated,	6.6810	13.8300

If we interpolate (by a process exactly similar) the same two radii for a dispersive ratio 0.60, we shall find respectively,

	1st Surface.	*4th Surface.*
For — 0.005 variation in Crown,	— 0.0338	— 0.5524
For + 0.004 variation in Flint,	+ 0.0015	— 0.2264
Total variation,	— 0.0323	— 0.7788
Radii in the Table, - - - -	6.7069	14 2937
Interpolated radii, - - - - -	6.6746	13.5149

Having thus got the radii corresponding to the actual refraction, for the two dispersive ratios 0.55 and 0.60, it only remains to determine their values for the intermediate ratio 0.567, by proportional parts. Thus,

		1st Radius.	*4th Radius.*
For	0.600	6.6746	13 5149
For	0.550	6.6810	13.8300
Differences,	+ 0.050	— 0.0064	— 0.3151

We then say 0.050 : 0.567—0.550=0.017 : : — 0.0064 : —0.0022
and 50 : 17 : : — 0.3151 : —0.1071

So that 6.6816 — 0.0022 and 13.8300 — 0.1071; or 6.6788 and 13.7229, are the true radii corresponding to the given data.

Thus, we have in the Crown Lens,

Focal length, = 4.330
Radius of one surface, = 6.6788
Index of Refraction, = 1.519

From which data it is easy to compute, by rules familiar to every optician, the radius of the other surface, which will come out 3.3868.

Again, in the Flint Lens, we have,

Focal length, = 7.635
Radius of one surfase, = 13.7229
Index of Refraction, = 1.589

whence we find 3.3871 for the radius of the other surface.

The four radii are thus obtained for a local length of 10 inches; and to obtain them for 30 inches, we have only to multiply them by 3, and we obtain finally, in the case proposed,

Radius of 1st Surface,	*of 2d,*	*of 3d,*	*of 4th,*
20.0364 Inch.	10.1604 Inch.	10.1613 Inch.	41.1687 Inch.

So that here the radii of the two adjacent surfaces scarcely differ more than $\frac{1}{1000}$th of an inch, and they may of course be cemented together, should it be thought desirable.

2. *On Achromatic Glasses made of Fluids.*

We have already had occasion to mention, with great approbation, the ingenious labours of Dr. Blair in the construction of fluid achromatic object-glsses, and the high degree of perfection which he gave to the telescopes that he constructed. As we still indulge the hope that some ardent mind will direct itself to this important object, and take up the subject where Dr. Blair has left it, we shall endeavour to explain the principle on which he proceeded in the construction of his compound object-glasses.

Having failed in discovering some highly dispersive medium which should refract the different rays of the spectrum in the same proportion as crown glass, he conceived the idea of employing this very imperfection to produce a perfect correction of colour. Since, the green rays were generally left out, (or were the *outstanding* rays, as Dr. Robinson expresses it) while the red and violet ones were perfectly united, it was obvious that, if an achromatic *concave* lens should refract the outstanding green *more* strongly than the united red and violet, while an achromatic *convex* lens should also refract the outstanding green *more* than the united red and violet, then two such achromatic lenses combined might unite the outstanding green with the red and violet, and produce a perfect union of all the colours. He therefore constructed an achromatic *concave* lens, as shown in Fig. 7. consisting of a concave crown glass lens *a b*, united with a convex lens *c b d*, of a dispersive fluid, which had the effect of uniting the red and violet rays, as shown in the figure, and leaving the green outstanding, and most refracted. He also constructed an achromatic convex lens, as shown in Fig. 8. consisting of a convex lens *g h*, of an essential oil, which disperses the rays in a lesser degree, combined with a concave lens *f e h g*, of an essential oil, which disperses the rays in a much greater degree. The convexity of this double lens is such as to unite, at a suitable distance, rays which diverged from the virtual focus of the double concave shown in Fig. 7. and consequently had a much shorter focal length than the other. Notwithstanding this, the deviation of the green ray from the united green and violet is equal in both lenses. For since the media of which the compound concave consists have the power of making the green rays deviate from the rest more than the media which compose the compound convex, when they refract it equally, it is necessary, when the refraction is unequal, (or when the refraction of the convex glass must predominate, so as to give a positive focus, as in a telescope) that the deviation of the green rays from the united red and violet must be equal in both, as shown in Figs. 7 and 8.

When two such compound lenses are placed in contact, as in Fig. 9. it is quite manifest that the equal and opposite deviations of the green ray produced by each separately, will correct one another, so that that ray will be precisely united with the red and violet, and thus form a pencil free of all secondary colour. The two plates of glass shown in Fig. 9. by the dotted lines *e*, *f*, *c*, *d*, and corresponding to the plates marked by similar letters in Figs. 7 and 8. are of course unnecessary, as the two fluids which these glasses confine are the same. Hence, such an object-glass requires only two fluid media and three glass lenses, which were necessary merely to correct the spherical figure.

Dr. Blair found that the best method of constructing an object-glass of this kind, was to divide the concave glass *a b*, Fig. 9. which is necessary for removing the secondary colour, by making two of the lenses, or all the three of them, concave meniscuses; that which is employed in Figs. 7, 8, 9. being intended only for illustration, although it will produce completely the required effect. This object was gained so completely in Dr. Blair's telescope, *that he could not discover* any colour by the most rigid test.

Dr. Blair had thus completely succeeded in his attempt to construct object-glasses perfectly free of the tints both of the primary and the secondary spectrum; but he still cherished the hope of discovering among the various dispersive fluids which nature presents to us, one which should separate the rays in the same proportion as glass.

Happening to try the muriatic acid mixed with a metallic solution, he found it better to form his compound convex, as shown in Fig. 8. of a combination of that fluid with glass, as he could thus correct the colour of the compound concave, and also the spherical aberration by a concave, which lessens the focal length of the convex only one-third.

While trying a compound concave formed with glass and *muriatic acid* alone, he found that this fluid possessed the property of producing an inverted secondary spectrum, or of giving a primary spectrum, in which the green rays were among the *most* refrangible; and hence he was led to the construction of a compound lens, as shown in Fig. 10, consisting of a concave fluid lens of muriatic acid placed between two lenses of glass. In this lens, which he actually constructed and used, *the rays of different colours were bent from their rectilineal course with the same equality and regularity as in reflexion.**

We cannot conclude this short account of the ingenious experiments of Dr. Blair,—experiments which have never yet received their due share of praise, without endeavouring to impress upon those individuals who have the power, the propriety of holding out some liberal encouragement to Dr. Blair, who has spent much money and time in those important inquiries, in order to induce him to convey to others the practical knowledge which he alone possesses of this important subject. The possession of telescopes of such a high character, (which is completely established by the unbiassed testimony of the late Dr. Robinson,) would be of immense consequence in our public observatories, and, when used at sea, might save to the country many a vessel, and to society many a valuable life. Even if these telescopes last only two or three years, their acquisition is still invaluable, and the liberality of the British government could not be more worthily displayed than in the patronage of a philosopher, who has done so much for this department of science, and has done it all at the expense of his time and his private fortune.

Art. V.—*On Dynameters for determining the magnifying Power of Telescopes.*

The exact determination of the magnifying power of telescopes is of the greatest importance for many optical and astronomical purposes. We have already seen, that in every refracting and Newtonian telescope, it is equal to the focal length of the object-glass, or speculum, divided by the focal length of the eye-glass; or of the equivalent single eye-glass, if the instrument has a compound eye-piece. As it is always difficult to measure the focal lengths of lenses with accuracy, and as, in the case of telescopes with compound eye-pieces, and in Gregorian and Cassegrainian telescopes, the difficulty of finding the magnifying power is considerable, it becomes a matter of consequence to have an easy practical method, or some simple instrument for determining the magnifying power of a telescope. The following method has been long in use for this purpose.

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* Dr. Blair was able to give an aperture of three inches to an object-glass of about nine inches focal length.

At the distance of 100 or 200 yards from the telescope, place a circular opening about an inch in diameter, cut out of a strong black card, or in a thin plate of brass, so that the light of the sky passes freely through it to the telescope. Cut a rectangular opening in a card, or in a plate of brass, so that the distance of its parallel sides is exactly equal to the diameter of the preceding circle. Having adjusted the telescope to distinct vision, direct it to the circular opening placed at the distance already mentioned, and with one eye view the magnified image of this circle, while with the other you look at the rectangular opening. Place the rectangular opening nearer to, or farther from the eye, till the magnified image of the circle exactly fills the rectangular opening seen with the naked eye, and when this is done with great nicety, measure the distances of the small circle and of the rectangular opening from the eye, and the quotient arising from dividing the first distance by the second will be the magnifying power of the telescope.

More than forty years ago, that ingenious and excellent artist, Mr. Ramsden, contrived a very simple instrument, called a *Dynameter*, for determining the magnifying power of telescopes. It was nothing more than a small double image micrometer, by which he measured the diameter of the emergent pencil of rays at the eye-hole. By dividing the exposed diameter of the great speculum, or of the object-glass of a telescope, by the diameter of the emergent pencil at the eye-hole, as determined by the instrument, the quotient will be the magnifying power of the telescope; for the diameter of the emergent pencil of rays is to the diameter of the speculum, or object-glass, as their respective focal lengths; and since the ratio of the two latter constitute the magnifying power, so must the equal ratio of the two former. Mr. Ramsden's dynameter is represented in Figs. 11. and 12. of Plate CCCCXL. In Fig. 11. is shown the external appearance of the instrument, and its plan is given in Fig. 11. A screw D, Fig. 12. attached to a graduated circumference E, works in a frame AA of brass, to which are fixed the tubes B, C, in Fig. 11. One of the semilenses B, B′, is fixed in the piece of brass H, through part of which at *o* works the screw *n*, while the other lens is fixed in the small plate BG, to the end of which at G is fixed the end of the screw *m*. This screw *m* works within *n*, and is left-handed, while *n* is right-handed. A spring IH leans against both the plates BG and B′H, to keep the screws connected with them free of any shake. These semi-lenses are near the point A in Fig. 11. at the bottom of the small tube B, upon which moves another tube C, the outer end of which is placed in contact with the outermost eye-glass of the telescope, when the diameter of the emergent pencil, or of the luminous disc which it forms, is to be measured. When the dynameter is in its place, the milled head D is turned in one direction, so as to draw the plate HB *o* to the *right hand;* but in consequence of the other screw *m* being left-handed, and fixed at G, it will screw out of the female screw within *n*, and as *n* is fixed, the screw *m*, and its attached plate BG, will move to the *left hand*, so that the two semilenses will separate by moving in contrary directions from the axis of the tube, and their separation is measured by the divided scale and index shown at S. Upon the principle, therefore, which we have described so fully in our article on ASTRONOMY, and in our article MICROMETER, this instrument measures the diameter of the emergent pencil of rays, or of the luminous disc which that pencil forms.

The dynameter of Ramsden has been greatly improved by his pupil, Mr. T. Jones of Charing Cross. In place of moving the semilenses in planes parallel to the axis of vision, Mr. Jones places each of them in a semitube, one of which is shown at *m*, and the other to the left hand of it, and these separate tubes, when acted upon by the micrometer screw D, turn round separate pivots, (one of which is shown at *o*) in a gimbal, or moveable ring, placed within the upper end of the tube BB, the extreme ends of the tube turning within this tube. The axis of the screw is solid, and is of bell metal, and the end C, next the graduated head, has threads of double fineness compared to the end within the tube, and it is constructed in such a manner that the semilenses move in contrary directions. A section across the semitubes carrying the semilenses is shown in Fig. 14. See Rees's *Cyclopædia*.

Without mentioning any of the preceding dynameters, the first of which was briefly described by the Rev Mr. Edwards in the *Nautical Almanack* for 1787, M. Biot has given an account of a method proposed by M Arago, for finding the magnifying power of telescopes. He takes a doubly refracting prism of rock crystal, such as those described in our article MICHROMETER, and placing it between his eye and the eye-glass, he views a circular white object through the telescope, and varies his distance from this object till the two images of it appear in contact. Hence he knows that this object subtends at the eye the same angle as that which is formed by the two pencils in the doubling prism, previously ascertained by looking at a disc of a given size, and at such a distance that the two images of it are in contact. But the diameter of the white disc and its distance being known, we have the angle which it subtends at the unassisted eye. Hence we have only to divide the *first* of these angles by the second, and the quotient is the magnifying power.

From the preceding observations, it is manifest that there are two methods of measuring the magnifying power of telescopes; the one by the *observer sitting in his own apartment*, and using the dynameter of Ramsden or Jones, and the second by *making an experiment out of doors*, as in the methods which have been long in use, and in that of M. Arago, which has nothing new in it excepting that of measuring an angle subtended by an object with the doubly refracting micrometer, in place of any other micrometer. If it is requisite, for want of a dynameter, to use a circular disc, and measure its distance and diameter, then the simplest possible method of finding the magnifying power is to observe, upon a distinct object, such as the face of a street, or a flat field, the exact space taken in by a diameter of the field of view of the telescope, when the object is magnified by it; and then to project by the eye the same field upon the same line, and determine the space which it occupies. These two distances will give the ratio of the tangents of the two angles, whose quotients represent the magnifying power of the instrument.

ART. VI.—*On the Space Penetrating Power of Telescopes.*

It has been generally believed that when a telescope is directed to any object, it produces no other effect than that of presenting a magnified picture to the eye; Sir W. Herschel, however, was led to question this opinion in the year 1776, when he had erected a Newtonian telescope of 20 feet focal length. Having directed it in the dusk of the evening to the dial of a distant church steeple, he found that he could see what o'clock it was, though with his naked eye he could not see the steeple itself. Dr. Herschel, therefore, considered, that though magnifying power was necessary to see the figures on the dial, it could require none to see the steeple, and he concluded that his telescope had a *power of penetrating into space.* "The distinction," says Dr. Herschel, "between magnifying power and a power of penetrating into space, could not but be felt long ago, though its theory has not been enquired into. This undoubtedly gave rise to those very useful short telescopes called night glasses. When the darkness of the evening curtails the natural penetrating power, they come in very seasonably to the relief of mariners that are on the look out for objects which it is their interest to discover. Night glasses, such as they are now generally made, will have a power of penetrating *six* or *seven* times farther into space than the natural eye." In order to illustrate the difference between magnifying and penetrating power, Sir William Herschel also states, that on the 10th of October, 1791, *he saw the fourth satellite and the ring of Saturn* in his forty feet speculum *without an eye-glass.* The magnifying power, as he remarks, could not exceed 60 or 70, but the great penetrating power made up for the lowness of the former, although the greatest part of the penetrating power must have been lost for want of a greater opening of the pupil, which could not take in the whole pencil of rays, which was about seven or eight tenths of an inch in diameter.

The following is a brief account of the principles on which Dr. Herschel composed his formula for determining the penetrating power of telescopes. He represents by l that portion of the light thrown out by luminous objects, which is actually used in vision either with the naked eye or with a telescope; but as the intensity of light decreases as the square of the distance of the luminous object, the expression for its intensity at any distance D, will be $\frac{l}{D^2}$. This quantity, however, will vary with the area of the pupil, or as the square of its diameter in natural vision, and in telescopic vision as the area, or the square of the diameter of the object-glass or mirror of the telescope. Hence calling a the diameter of the pupil, and A the diameter of the object-glass or speculum, the quantity of light admitted to the eye will be expressed by $\frac{a^2 l}{D^2}$, and the quantity admitted through a telescope $\frac{A^2 l}{D^2}$. When the pencil of light transmitted by the telescope to the eye, exceeds the aperture of the pupil, the expression $A^2 l$ will fail; and hence if m is the magnifying power, $\frac{A}{m}$ should never exceed a the diameter of the pupil. If no light therefore was lost by reflexion or refraction through the mirrors and lenses of telescopes, the artificial power of penetrating into space with telescopes would be to the natural one as $\frac{A^2 l}{D^2}$ to $\frac{a^2 l}{D^2}$, or as A to a; but as a considerable proportion of light is lost (see Chap. vii. p. 758, 760.) in reflexion and refraction, we must find a correction x to be applied in consequence of this loss.

As the brightness of luminous objects is inversely as the squares of the distances, the penetrating power must be as the square roots of the light received by the eye; and in natural vision will therefore be expressed by $\sqrt{a^2 l}$. In reflecting telescopes where two specula are used, there will be an obstruction of light corresponding to the diameter of the smaller speculum, and calling b the diameter of that speculum, $A^2 - b^2$ will express the real quantity of incident light. But as this light is diminished in the ratio of 1 to x, a fractional co-efficient to be determined by experiment, we have, $\sqrt{(x\, l \times \overline{A^2 - b^2})}$; and calling $l = 1$, and dividing by a, we shall have $\frac{\sqrt{(x \times \overline{A^2 - b^2})}}{a}$; for the penetrating power of reflecting telescopes with small mirrors, or $\frac{\sqrt{x A^2}}{a}$ in refracting telescopes, and reflectors used with the front view.

The 20 feet *Newtonian telescope* above mentioned, had an aperture of 12 inches, or 120 tenths, and the small mirror an aperture of 1.5 inches, or 15 tenths. Now, Sir W. Herschel found, from experiment, that only 45242, out of 100,000 rays, reached the eye after two reflexions; and that with a single eye glass, 94825 rays out of the 100,000 were transmitted, consequently with two reflectors and one eye-glass, the rays that reach the eye will be ·4290, the incident light being 1, and with two reflectors and two eye-glasses, ·40681. The value of x, therefore, in the 20 feet Newtonian telescope, is ·429. consequently, calling the aperture of the pupil $= 2$ tenths, the penetrating power is $\frac{\sqrt{(\cdot 429 \times (120^2 - 15^2))}}{2} = 39$, so that the telescope rendered the steeple visible in consequence of its having a penetrating power 39 times greater than that of the naked eye.

In the case of the *night glass* already mentioned, where A is 2½ inches, or 25 tenths, and $x = .853$, for 3 refractions, (See p. 760,) we have its penetrating power $= \frac{\sqrt{\cdot 853 \times 25^2}}{a} = 6{\cdot}46$ or $7{\cdot}33$, calling $a = \frac{A}{m}$; and m being 7 or 8 times; for the usual size of a, viz. 2 tenths, does not admit the breadth of the optic pencil, which in that case is 3⅛, or 3$\frac{4}{7}$ of an inch. For farther information on this subject, see the *Phil. Trans.* 1800, vol. xc. p. 49.

ART. VII.—*On the Eye-Pieces of Telescopes.*

We have already had occasion to describe several of the eye-pieces of telescopes, both single and compound. Single eye-pieces consist of single lenses, either convex or concave; and their form should be either plano-convex, or plano-concave, or exactly such as we have shown in a former chapter will give a minimum error of sphericity.

The great importance of doing this, will appear from the following results obtained by Mr. Herschel. The minimum aberration produced by the eye-lens of the best form being 1, that of the other lenses will be,

	Aberration.
Plano-convex, plane side first - - -	4.2
Plano-concave, plane side first - -	4.2
Do. convex or concave surface first -	1.081
Double convex or double concave -	1.567
Best form - - - - - - - - - -	1.000

As it is desirable, however, to reduce the spherical aberration below the amount of its minimum in single lenses, we must have recourse to two lenses placed together. Mr. Herschel has shown, that the minimum aberration which can be produced by two convex lenses placed together will be 0 2481, or one fourth of that of a a single lens in its best form; and that this diminution will be effected by two plano-convex lenses, as in Fig. 15. the focal length of the first being to that of the second as 1 to 2.3. If the lenses are of equal foci, the aberration will still be so low as 0.6028, or reduced nearly one-half.

In order, however, to destroy the spherical aberration altogether by two lenses put together, Mr. Herschel has shown that they must have the form represented in Figs. 16 and 17. the convex sides being turned to the eye when used as lenses, and to the parallel rays when used as burning-glasses. The following are the focal lengths and radii of these lenses.

	Fig. 16.	Fig. 17.
Focal length of the first lens	+ 10.000	+ 10,000
Radius of its first surface	+ 5.833	+ 5 833
Radius of its second surface	— 35 000	— 35 000
Focal length of the second lens	+ 17.829	+ 5.497
Radius of its first surface	+ 3 688	+ 2 054
Radius of its second surface	+ 6.291	+ 8.128
Focal length of the combination	+ 6 407	+ 3.474

Mr. Herschel has remarked, that in a burning-glass, the destruction of the aberration of rays parallel to the axis, is of the greatest importance. In order to try this, he had two lenses ground to the radii in the first column of the above table. They were about three inches in aperture, and when combined as directed above, the aberration was almost totally destroyed. Their combined effect as a burning-glass was decidedly superior to the first lens used alone.

In eye-glasses and magnifiers, when we wish to examine a *minute object*, Mr. Herschel is of opinion, that perfect distinctness in the central point is of more consequence than extent of field, and that too much pains cannot be taken to destroy the central aberration.

In those cases, on the contrary, where periscopic effects are required, such as in spectacles, reading-glasses, magnifiers of moderate power, and eye-glasses for certain astronomical purposes, the correction of the central abberration may be sacrificed without inconvenience. The best periscopic combination which Mr. Herschel found, was a double convex lens of the best form, but placed in its worst position for the lens next the eye; and a plane-concave, whose focal length is to that of the other as 2.6 to one, or as 13 to 5, placed in contact with its flatter surface, and having its concavity towards the object, as in Fig. 18. The aberration of such a lens for rays parallel to the axis, is no less than twenty-two times that of a single lens in its best position; yet upon forming such a combination accidentally, Mr. Herschel was surprised at the remarkable extent of oblique vision,—the absence of fatigue in reading with it,—and the great destruction of colour arising from the opposition of the prismatic refractions of the two lenses. The focal length of the compound lens was 1 84 inch. The field of tolerably distinct vision was 40° from the axis, and the letters of a book might be read with management as far as the 75th degree. In making such combinations, the lenses should be very thin, and the eye applied as close as possible.

The construction of compound achromatic eye-pieces, has not yet been investigated with that attention which it deserves. In our article on achromatic telescopes, we have given an account of the construction of such eye-pieces with two or three lenses; but little has been written on the subject of those with four lenses, and though Boscovich has begun the inquiry in his dissertations, he acknowledges that much yet remains to be done.

The achromatic eye-piece of two lenses is shown in Fig. 1. where AB is the achromatic object-glass, and CD, EF, two eye-glasses. The rays AC, which pass through the centre of the object-glass, are dispersed at C; C r being the red, and C v the violet ray. As the red ray C r falls upon the lens EF at a greater distance from its centre than the violet ray C v, and where the inclination of the refracting surfaces is greater, it will suffer a greater refraction from the lens EF, and this excess of refraction may be made to balance or compensate its inferior refrangibility, so that the rays may emerge from the lens E in the parallel directions E r', E v'. Boscovich has shown, (and the accuracy of his result may be easily determined by tracing the rays trigonometrically through the lenses) that this parallelism of the red or violet rays may be produced by making CD, EF, two convex lenses of the same kind of glass, the first of which, CD, has its focal distance and aperture triple that of the second; and if the distance between the two is equal to double the focal distance of the second, the first lens must be placed within the focus of the object-glass, and at a distance from it equal to the half of its own focal length. The magnifying power will be double of that of the first lens alone, and the field also the same as that of the first lens.

Through this eye-piece, the object will obviously be inverted. It might be made erect by two eye-glasses, placed at a greater distance, so that the rays, C r, C v, may cross the axis, and fall upon the lower half of the lens EF; but the colours cannot be corrected by such a combination.

In examining the problem of two eye-lenses of the same glass more generally, Boscovich has proved that they may be rendered perfectly achromatic, whatever be their focal length, provided their distance be equal to half the sum of their focal lengths, or, what is more accurate still, when their distance is equal to half the sum of the focal distance of the eye-glass, and the distance at which the field-glass would form an image of the object-glass.

The method of correcting the colour with three lenses will be understood from Fig. 2. where AC is a ray passing through the centre of the object-glass, and incident upon the first eye-glass CD at C. It is there refracted in the direction CR, CV, the former being the red, and the latter the violet ray; and these rays are again refracted by the lens EF, in the directions R r, V v. If b is the anterior principal focus of EF, the rays diverging from C will be collected at r; but as the violet ray CV will be more refracted at V than the red ray, it will cross the red ray R r somewhere at m, between R and r. If the image, therefore, formed by the object-glass, were formed exactly at CD, there would be an image at $m\,n$ free of all colour. But the third eye-glass GH will not enable us to see the image $m\,n$ free of colour; for the violet ray $m\,v$ will be more refracted than $m\,r$. It may be rendered parallel to $m\,v$, however, by making the refraction at r such as to have its accompanying dispersion of a proper magnitude. This effect will be produced, as Boscovich shows, if three simple and equal lenses of the same glass are arranged in such a manner, that the distance of the two first is equal to double the focal distance of either, and the distance between the second and third equal to $2\frac{1}{2}$ of their focal distances. In this case the magnifying power is the same as if the third lens alone had been used. Another system of three eye-glasses is given by Boscovich, in which the two first have their focal distances equal, and the third its focal distance *one half* of each of the other two; but it may be greatly improved, by making the third lens consist of two lenses in contact, each of which has the same focal distance as the first and second.

In examining the question more generally, Boscovich found that an achromatic eye-piece may be formed out of three lenses, whatever be their focal distances, provided the distance of the first and second is equal to the sum of their focal distances, and the third placed at a distance from the second greater than the sum of their focal distances. This excess of distance is equal to the square of the focal distances of the second, divided by the sum of the focal distances of the first and second lenses. (See the formulæ under ACHROMATIC TELESCOPE.) Boscovich is of opinion, that the simplest construction of these glasses is that in which the focal lengths of the first and second lenses are equal, and that of the third shorter. In this case, the distance of the third lens from the second should be equal to its own focal length, together with $1\frac{1}{2}$ the focal length of the first or second lenses. The magnifying power of the eye-piece will increase as the focal length of the third lens is diminished, and the field of view will diminish. The longer we make the focal lengths of the two first lenses, the less will dust be seen on the lenses, as the first lens becomes more distant from the focus of the object-glass. A greater aperture, and consequently a greater field, will be obtained, by making the third lens consist of two of the same focal length.

The progress of a heterogeneous ray of light through an achromatic eye piece of four lenses, is shown in Fig. 3. where $n\,m$ is the image formed in the focus of the achromatic object-glass, and n C a ray proceeding from the extremity n. The ray n C is dispersed, so that CR is the red ray, and CV the violet. After refraction through the second lens ED, they proceed in the directions R r, V v. The action of the third lens GH causes them to cross at ν, and by the fourth lens KL they are rendered parallel in the directions $r'\,r''$, $v'\,v''$. One of the best combinations of four glasses is composed, according to Boscovich, in the following manner:

Focal length of the lenses	1st, or CD;	2d, or EF;	3d, or GH;	4th, or KL
	14 lines.	21 lines	27 lines.	32 lines.
Distances	23	44	40	
Apertures	9	13	11	12

Focal length of the equivalent eye-glass 15 2-3 lines.

In this combination there is still a separation of colours amounting to 7″.16; but this may be removed by a slight change in the distance of the lenses, or in the focal length of the one next the eye.

In Fig. 4. we have represented an eye-piece of four glasses, as made by Ramsden for a small telescope of $8\frac{1}{2}$ inches focal length, $1\frac{1}{10}$ of aperture, 2° 5′ of field, and 15.4 of magnifying power. The following are the focal lengths and distances of the glasses:

Focal length $A\,a = 0.0775$; $B\,b = 1.025$; $C\,c = 1.01$; $D\,d = 0.7$
Distances $AB = 1.18$; $BC = 1.83$; $CD = 1.105$

The apertures in the figure are one-half larger than they are in reality. This eye-piece, which was first described by Dr. Robison, was, as he observed, perfectly achromatic, and the colours were united. not precisely at the lens C, but $\frac{1}{20}$th of an inch nearer the eye-glass.

In the construction of achromatic eye-pieces, the proper distance of the lenses should be ascertained by placing them in separate tubes, and discovering from actual experiment the exact positions at which the colours are corrected. Dr. Robison recommends that eye pieces should be made with extravagant apertures to increase the aberration, and that the artist should have a number of sets of lenses of the same focal length, but of different forms; and he proposes that they should be tried by employing them as the magnifying glass of a solar microscope. Two pictures being formed on the same screen, could then be accurately compared, and the eye could form a decided judgment of their respective qualities.

With regard to the form of the lenses which is best fitted to correct the spherical aberration, Boscovich remarks that they should be made of common glass, and plano-convex, or nearly so, and that the plane side should be always turned to the eye, excepting in the case of the second lens, whose plane side ought to be turned towards the object.

In the construction of eye-pieces, it is a matter of the greatest importance to have each lens nicely centered, and to have the axes of all the lenses accurately coincident with one another. Much less attention has been paid to this point than it deserves, and we are strongly persuaded that there is scarcely a compound microscope, or an eye-piece, that might not be considerably improved by a rigid attention to this kind of adjustment. We have already had occasion, under our article MICROSCOPE, to direct the reader's attention to this subject, and there will be no difficulty in effecting it, by means of the image of a bright point, formed by reflexion from the surfaces of the lenses, as described in the following article.

ART. VIII.—*On the adjustment of the Lenses of a Triple Achromatic Object-Glass.*

The accurate adjustment of the lenses of an achromatic object-glass is not less important than that of the lenses which compose the eye-glasses. A very excellent method of doing this has just been published by Dr. Wollaston, which merits the particular notice both of the optician and the practical astronomer. If we take out the eye-glasses of an achromatic telescope, and placing the eye immediately behind the object-glass, look at a candle set close to the eye-hole, we shall observe, if the object-glass is triple, *ten* images, as shown in Fig. 5. *two* beyond the candle, *four* in regular succession nearer the eye, and *four* very small ones, close together, in front of the object-glass, and within the tube. Other *five* images may be seen, without the tube, as in Fig. 6. by withdrawing the eye, and using a lens L, as in Fig. 6. These different images obviously arise from reflexion from the curved surfaces of the three lenses; and if the lenses are perfectly adjusted, all the images will be arranged exactly in the same straight line, while any error of adjustment will be indicated by a deviation from that rectilineal arrangement.

In order to explain distinctly the origin of each of the above images, Dr. Wollaston has marked, as in Fig. 7. those surfaces which have their concavities *towards the tube*, with large letters, A, B, C, and those curved in the opposite direction, with the small letters *d*, *e*, *f*, so that in Fig. 8. which points out the origin of each image, a similarity of source in the several groups will be found from a similarity of notation. Thus BC, or *d e* shows that the image is produced from a combination of curvatures in the same direction; unequal letters, with the smallest first, as *d* C, show that the image is produced by opposite curvatures, giving a negative focus; while the unequal letters, with the largest first, as B *f*, show that the image is produced by opposite concavities, forming a positive focus behind the glasses. The origin of these images was determined by giving a small motion to one or other of the convex lenses, in which case all the images dependent upon that lens are displaced or inclined in the same line.

For the purpose of having a complete command of each lens, Dr Wollaston had a large cell constructed for his lenses, with two pair of adjusting screws, placed at right angles to each other, and applied to the edges of each glass; so that when the images had been first brought into the same vertical plane, by means of one set of screws opposed to each other in the horizontal position, the series might next be adjusted to the same horizontal line by the screws placed above and below, at right angles to the former.

By the means which have now been explained, Dr. Wollaston repeatedly restored his object-glass to correct performance, after having removed it from its cell.

In order merely to see the series of images above described, the flame of a candle, not confined by an eye tube, gives a series of sufficiently conspicuous images; and in order to see that these images are not very irregular, an eye-hole, one-fourth, or one-fifth of an inch may be used. When the adjustment is to be made by candle light, a single eye-glass $\frac{1}{10}$th or $\frac{1}{15}$th of an inch focus, was found to give a series of sufficiently distinct images; but in order to complete a very nice adjustment, Dr. Wollaston employed the light of the sun with an eye-glass of $\frac{1}{20}$th or $\frac{1}{30}$th of an inch focus. Even if the sun's light falls very obliquely on a small eye-glass, the external images A *d*. A *f*, are mere luminous points, so that any error in their relative position is immediately detected.

With this test as a guide for final adjustment, and without farther revision, Dr Wollaston's telescope, of 45 inches focus, and made by Dollond in 1771, was capable of either separating very small and nearly equal stars, as those of 44 Bootis, and σ Coronæ, or of exhibiting the minute Secondaries of β Orionis and 24 Aquilæ, with as much distinctness as the state of the air will admit. See *Phil. Trans.* 1822, p. 32.

SECT. XIII.—*Description of the Dichroscope.*

We have given the name *Dichroscope* to those instruments which exhibit the two complimentary colours of polarised light, from *δυο*, *two*, *χροα*, *colour*, and *σκοπεω*, to *see*.

The dichroscope, in its original state, is nothing more than a portable apparatus for exhibiting the experiments of M Arago and Dr. Brewster on the colours of crystallized plates, as will be seen by comparing Fig. 9. Plate CCCCXLII. with Fig. 3. of Plate CCCCXXXVI. (See Prop. XXVI. p. 720.) The apparatus, as brought from Paris in 1814, consisted of a piece of black glass, or black japan, MN, which was carried in the pocket, and of a separate tube ABE, containing a plate, AB, of rock crystal, cut perpendicular to the axis, and one of Rochon's doubly refracting prisms, *c d*, made of rock crystal, so as to give only two images polarised in opposite planes. When the tube ABE was directed to the black plate, MN, at an angle of about 57°, as nearly as could be guessed, the complementary colours of the crystallized plate AB, were seen, which varied upon turning round the tube. If the aperture AB was small and round, the two images of it coloured with the opposite complementary colours were completely separated; but if the aperture was large, and either round, or in the form of a star, or any other shape, the two images overlapped each other, and the overlapping parts were always white, in consequence of the mixture of the two complementary tints.

The form in which Dr. Brewster constructed the dichroscope, is shown in Fig. 10. where the plate MN, composed of six or more of the thinnest and most transparent plates of glass, is made to move round a hinge at the end AC of the tube ABDC, so as to reflect or transmit a strong beam of polarised light, RS, along the axis of the tube; *n* is a convex eye-glass placed next the eye, *o* an aperture of a circular or any other form, in the focus of the lens o; *m* a flat piece of topaz or rock crystal,* not much larger in diameter than the pupil of the eye, and cut in the proper direction from the crystal; and BD a prism of nearly the same diameter formed out of rock crystal in the manner long ago described by M. Rochon,† so as to produce the greatest separation of the images, or, what is still simpler, a prism of calcareous spar having the refraction and dispersion as much as possible corrected by an opposite prism of balsam of Tolu, or indurated Canada balsam. When the instrument is thus fitted up, the rays RS, polarised by reflexion from the plates MN, or by transmission through them, are arranged into their complementary colours by the crystallized plate *m*, and are afterwards separated into two distinct pencils by the double refraction of the prism BD. An eye, therefore, placed at *n*, will see two distinct images of the aperture *o*, and the colour of the one image will be complementary to that of the other. These images will exhibit alternate variations of tint by turning round either the tube, or the polarising plates MN. If the two images overlap, the parts that overlap will be white, in consequence of the combination of the two opposite colours. The object of using the lens *n*, is to shorten the tube; but if we remove the eye-glass, the aperture *o*, may be made of any size, and placed at any distance from the eye.

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* A thin film of sulphate of lime is much better than any other mineral, as it requires no trouble to prepare it Topaz is preferable to rock crystal, as the latter very often gives false tints, from a want of uniformity of structure.

† *Journal de Physique*, 1801. *Mémoire sur le Micrometre de Crystal de Roche.* Paris, 1807.

In Fig. 11. we have represented another dichroscope, constructed by Dr Brewster, and so very simple, that any person can make it for himself; MNOP is a tube about two inches long attached to a ball and socket. The end MO of the tube carries an aperture of any form, and the ball CD contains two prisms of calcareous spar, separated by a film of sulphate of lime, so placed that each pair of the four images is tinged with the complementary colours, as described in Sect. IV. p. 721. A lens L is cemented either upon the anterior or posterior surface of the compound prism, or may be kept separate from the prism at L; but, whatever be its position, it must always enable the eye at E to see the aperture with perfect distinctness, and the focal length of the lens must be so adapted to the magnitude of the aperture, that the images of it can be sufficiently separated by the universal motion of the ball CD. The interior of the tube being covered with a black pigment, the instrument is ready for use. If we direct it to the sky, or to any luminous object, four brilliantly coloured images of the aperture will be distinctly seen, the colour of the two middle images being complementary to that of the two extreme images. By moving the ball in the socket, the colours will constantly change, and the images will sometimes overlap, and sometimes separate, exhibiting the finest variety of hues, and pleasing the eye by their combinations, and by the soft harmony of their contrasts.*

If we use a perfect crystal of calcareous spar, with an interrupting vein, as described in Sect. XVII. p. 746. and substitute it in place of CD, we have a *natural dichroscope* of the most perfect kind.

In the instrument where it is necessary to polarise the light by black glass, or japanned metal, there is no less than $\frac{12}{13}$ths of the incident pencil lost by reflexion, while in the preceding instrument the light lost by transmission is very small. From this cause, the brightness of the colours is incomparably greater, and they may even be distinctly seen in candle light, by directing the aperture to a piece of white paper held near the candle.

In Fig. 12. is represented another instrument of great advantage in carrying on very delicate experiments on the polarisation of light. In comparing the quantities of light polarised in the plane of reflexion by different metals, we derive very little aid from examining the partial evanescence of one of the images. The intensity of the complementary colours is a much more delicate measure of the portion that has received this character. The method of doing this is shown in the figure, where ABD is a tube about eight or nine inches long, supported upon a stand. An equal and unbroken plate of *sulphate of lime*, which gives an uniform tint in every part of its surface, is cemented with Canada balsam between two plates of parallel glass, and is placed at the end AB of the tube, exposing two circular apertures *m*, *n*, to the incident rays. At the other end of the tube is a piece of black glass *o p*, inclined at an angle of 33° to the axis of the tube, and having a motion of rotation round that axis. When polarised light is transmitted through the apertures *m*, *n*, and reflected from the surface *o p* to the eye, these apertures will appear equally coloured in every position of *o p*, the colour in one quadrant of its circular motion being complementary to that in the adjacent quadrants. If we now wish to compare the quantity of polarised light in a pencil reflected at an angle of 80° from *silver*, with the quantity polarised at the same angle by *steel*, we have only to transmit the one pencil through *m*, and the other through *n*, and the intensity of the colours will show which of the two contains the greatest quantity of polarised light. Or if we diminish the inclination of the steel surface till the colours of the two apertures are equally intense, we obtain the angles of incidence at which *steel* and *silver* polarise equal quantities of light in the plane of reflexion. By using two plates of black glass having a variable inclination to the axis of the tube, we may allow the light to fall at equal angles upon the two metals, and thus ascertain the different inclinations of the plates of glass at which the two apertures exhibit the same intensity of colour.

If we wish to see the whole progression of the colours of crystallized plates, from the blue of the first order up to the white, or mixture of all the colours, we have only to use a thin plate of calcareous spar cut perpendicular to the axis; or, what is still better, a perfect natural crystal of calcareous spar, or the *chaux carbonaté basée* of Hauy, in which the faces are not only perfectly polished, but are truly parallel to one another, and truly perpendicular to the axis of the rhomb. This plate may be put into a tube like that in Fig. 10. and used with a singly polarising crystal, or with a double prism, and by varying the inclination of the plate to the axes of the tube, it is easy to observe the primitive and the complementary tints of any of the orders of rings. Quartz, mica, topaz, and other crystals, are quite unfit for this purpose, as the tints of the first are disturbed by the secondary tints of circular polarisation, while those of the other two deviate from the tints of Newton's scale.

Since the complementary colours are those which always harmonise best with one another, as explained at great length in our article on ACCIDENTAL COLOURS, the dichroscope becomes an instrument of great use in selecting the different colours which are best adapted to each other, either in articles of dress or household furniture. If, for example, we wish to find the colour which harmonises best with a golden orange, we have only to turn the instrument till the orange colour appears in the one image, and we shall find the other image tinged with a sky blue, which is the colour required.

SECT. XIV.—*On Photometers.*

Although the term *Photometer*, from φως, *light*, and μετρον, *a measure*, has been introduced by Lambert as the name of an instrument, yet we can scarcely say that any such instrument exists.

Bouguer and Lambert had no instrument by which they measured the intensity of light, but employed merely the methods and the apparatus which we have already described in Chap. VII. p. 758.

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* The phenomena will admit of many beautiful variations, by using several films of sulphate of lime, having their axes variously inclined to one another.

An ingenious method of measuring the comparative intensities of the light emitted by luminous bodies, was proposed in the year 1794 by Count Rumford. The two burning candles, or lamps, or any other two lights which were to be compared, are placed at equal heights, on two moveable stands, in a darkened room. A sheet of clean white paper, equally spread out, is fastened on the wainscot on one side of the room, at the same height from the floor as the lights; and the lights are placed over against this sheet of paper, at the distance of six or eight feet from it, and six or eight from each other, in such a manner that a line drawn from the centre of the paper, perpendicular to its surface, shall bisect the angle formed by lines drawn from the lights to that centre. In this case, the one light will be in the line of reflexion of the other, the sheet of paper being considered as a plane reflecting mirror.

When this adjustment is made, a cylinder of wood, about six inches long, and one-fourth of an inch in diameter, is held vertically about two or three inches before the centre of the sheet of paper, so that the two shadows of the cylinder produced by the two lights may be distinctly seen. If these shadows have unequal densities, the light whose corresponding shadow is the densest must be removed farther off, or the other must be brought nearer to the paper, till the densities of the shadows appear exactly equal; or, what is the same thing, till the densities of the rays diverging from the two lights are equal at the surface of the paper. When this happens, the squares of the distances of the lights will be to each other as the real intensities of the lights.

In order to convert this instrument into a photometer, Count Rumford received the shadows of the cylinder on he back part of a wooden box, open in front to receive the light. Having found it inconvenient, however, to compare two shadows projected by the same cylinder, he made use of two cylinders fixed perpendicularly to the bottom of the box, and distant from the back of it $2\frac{2}{10}$ths inches, while their axes were placed at the distance of three inches. These two cylinders projected four shadows on the back of the box, (called the *field* of the instrument,) two of which are in contact exactly in the middle of the field, and are the two whose densities are to be compared; the two outer ones being made to disappear, by falling without the field on a blackened surface. In one of Count Rumford's instruments the cylinders are $\frac{4}{10}$ths of an inch in diameter, and $2\frac{2}{10}$ths inches high, and the field is $2\frac{7}{10}$ ths inches wide. In this instrument, the paper which forms the field is pasted on a small frame of very fine ground glass, and the glass thus covered is let down into a groove made to receive it in the back of the box.

For the purpose of making the shadows always of the same diameter, which is not the case unless the lights have the same diameter, the cylinders are moveable about their axes, and to each is added a vertical wing $\frac{11}{20}$ths of an inch wide, $\frac{1}{10}$th of an inch thick, of the same height with the part of the cylinder within the box, and firmly fixed to it from the top to the bottom. By means of these wings the widths of the shadows are augmented so as to fill the whole field of the photometer. The cylinders, which are made of brass, are turned round by taking hold of the ends which project below the bottom of the box.

For a full account of this instrument we must refer the reader to the *Philosophical Transactions* for 1794, p. 67.

The celebrated M. Lambert first suggested the thermometrical photometer, an instrument which measures the intensity of light, on the supposition that the quantity of light and heat in any beam of the solar or other rays, are invariably proportional to each other. He saw, however, the imperfections of the instrument, and remarked that its use was too circumscribed, as it was impossible to measure with a thermometer the brightness of the lunar rays.*

The same principle was afterwards applied by Mr. Leslie to an air thermometer, but for the reason assigned by Lambert, it can never be considered as affording a measure of light See Lambert's *Photometria*, p. 5, 6; and Leslie *On Heat*, p. 103.

SECT. XV.—*Description of the Optigraph.*

The optigraph, which is a telescope made for the purpose of copying landscapes, was, we believe, originally suggested by Dr. Darwin, and improved by Mr. Watt, who informed the writer of this article that he put it into the hands of the celebrated Mr. Ramsden, for the purpose of being constructed.

The optigraph, as constructed by Mr. Ramsden, was afterwards improved by Mr. Thomas Jones, who has given the following description of it.

"Fig. 13. is a perspective view of the optigraph. A represents the drawing-board, on the outside frame of which is fixed the pillar of the instrument B, by a clamp *a*; C is a tube (sliding in the pillar,) on the top of which is fixed, by means of a screw *c*, the frame D; at the end of this frame is a plane mirror E, beneath which is suspended, by a universal joint, the telescope F, of which G is the eye-tube. H are sliding tubes, capable of being shortened or lengthened in the same proportion as the inside speculum *e*, (Fig. 14.) which is fixed to any place by the clamp screw E. The pencil L, of which *h* is the handle, slides perfectly easy, without shake, in the tubes H, and is so contrived as to have all the freedom of a pen when held in the hand for use.

Fig. 14. represents a section of the telescope, being the principal part of the invention. The rays from an object entering the plane mirror *a*, are reflected into the telescope, passing through the object-glass *b*, and entering the speculum *c*, are reflected through the eye-glass *d*, to the eye at *e* : *f* is a piece of parallel glass, with a small dot on its centre, exactly in the focus of the eye-glass *d*.

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* The following is the passage in the *Photometria*, where this instrument is described:—"Optandum certe esset, ut excogitaretur photometrum thermometro analogum, quod lumini expositum ejus intensitatem atque claritatem indicaret. Enimvero ipse oculus nobis ejus sistit exemplar, quippe pupillae apertura luminis sequitur magnitudinem ac claritatem, et utrique sese accommodat. At magnopere dubitandam artem in hoc negotio naturam posse imitari. Vix enim parabitur materia sensibilitate fibrillarum oculi gaudens motuique luminis cedens, etiamsi hujus claritas sit perexigua. Non me latet, hunc in finem sumta fuisse a pluribus experimenta, quibus demonstrare conati sunt, motum luminis esse sensibilem, cum arena vel lamina chalybea foco lentis causticæ vel speculi ustorii exposita a vi radiorum solarium agitaretur. Merito enim dubitare licet, lumini an calori effectus iste adscribi debeat, atque etiamsi cum a solo lumine proficisci concedamus, cum tanta requiratur radiorum densitas, parva certe remanet spes, idem obtineri posse, ubi mensurandum venit lumen longe debilius. *Quodsi vero lumen sumatur solare, atque ponere liceat, hujus calorem in eadem ratione minui vel intendi, qua minui et intendi potest ejus densitas thermometrum utique photometri vices sustinere poterit. At nimis arctis ejus usus circumscriptus erit limitibus. Quis enim ope thermometri luminis lunaris detegit claritatem?*"—Lambert's *Photometria*, p. 5, 6.

Fix the drawing board to the table, (by a clamp which is packed in the box,) so that the surface of the mirror E is nearly parallel to the object; then take hold of the handle *h*, and hold the pencil on that part of the paper where you would wish the centre of your drawing, or any part of it, to be. Then place your eye at the eye-tube G, and with your left hand alter the inclination of the mirror E, until the small dot, described at *f*, in Fig. 14. is on some particular part of the object that you wish to begin with, adjusting the telescope to distinct vision by the milled head P. Then, by moving your hand (having the pencil) you pass the dot seen in the field of the telescope over the object, the pencil marking it at the same time on the paper.

To make your drawing larger, pull out the tube of the pillar C, Fig. 13. and fix it with the screw *e*; then pull out the sliding tubes H, till the pencil is within half an inch of the paper, (in the middle of the board,) and proceed as formerly.

To make the drawing smaller, shorten the tubes C and H, by sliding them in, and proceed as before." See *Phil. Mag.* vol. xxviii. p. 66.

Sect. XVI.—*Description of the Teinoscope.*

The word *teinoscope* from τεινω, *to extend*, and σκοπεω, *to see*, is an instrument constructed by Dr. Brewster, for examining an object in a state of extension, or for altering the lineal proportions of objects. When two prisms of crown-glass are put together so as to produce refraction without colour, as described in Prop. XIII. p. 677. it is obvious that the lineal dimensions of objects are extended or magnified in the plane of refraction, so that the elevation of a building or any other object is magnified in length, while its breadth remains the same.

By moving one of the prisms in the plane of refraction, so as to go on each side of the achromatic position, the proportion of the length to the breadth of the object was altered, though the colour was, of course, not entirely corrected.

In order to obviate this inconvenience, Dr. Brewster contrived a compound instrument of four prisms, as represented in Fig. 15. where AB is a prism with a variable refracting angle, as used by Clairaut for measuring dispersive powers. It consists of two prisms A, B, of the same material, united by two cylindrical surfaces *c*, *d*, *e*, *f*, so that by the motion of the concave cylindrical surface of B upon the convex one of A, the two plane surfaces MN form different angles with one another. Another prism C, of the same glass, is placed as in the figure, so as to correct the colour of AB, when the inclination of M and N has its mean value.

If we now look at any object through the faces *m*, *n*, M, N, it will be quite free of colour, and its length (if in the plane of refraction,) will be magnified or extended, so that we can judge whether its form would be improved by varying its longitudinal dimensions. If we wish to examine its appearance when its length is made greater or less in proportion to its breadth, we have only to enlarge or diminish the inclination of the faces MN, and then correct the colour, by placing the prism C at a greater or less distance from M. In this way we may ascertain the exact relation between the length and breadth of an object, which is most agreeable to the eye, in place of discovering it by a succession of designs.

As the effect of the different designs, however, possessing different ratios of length and breadth, could not be recollected so as to be brought into direct comparison, it became advisable to have two instruments adjusted to give the proportions which it was required to compare; and by combining the two instruments together, we obtained the additional advantage of enlarging the extending power of each instrument, when they were placed similarly, or in the same plane; and of obtaining a variation in the breadth of the object when they were placed transversely, or in rectangular planes. By such means Dr. Brewster had it in his power to vary either the length or breadth of the object, and to produce, within moderate limits, any change that was required in the ratio of its lineal dimensions.

In constructing these instruments for actual use, it is not necessary that the prism C should be made of the same kind of glass as AB. The power of the instrument would be greatly increased by making C of fluor-spar or rock-crystal, or the colourless topaz of New Holland,* on account of their low dispersive power. The reflexion of light at the cylindrical surfaces of AB may be removed by introducing a film of oil of the same refractive power as the glass, and the motions of the prisms N and C may be so connected, that the achromatic position for different angles of the variable prism may be obtained by turning a single screw nut.

By combining prisms in this way, Professor Amici of Modena has obtained a magnifying power sufficient for an opera glass. See *Memorie della Societe Italiana*, tom. xix.; and the *Edinburgh Philosophical Journal*, vol. vi. p. 334.

Sect. XVII.—*Dr. Wollaston's Instrument for Measuring the Refractive Powers of Bodies.*

This ingenious instrument was suggested to Dr. Wollaston by the prismatic eye-glass of Sir Isaac Newton, which depends on the total reflexion of light at the inner surface of a refracting medium.

"Since the range of inclination," says he, "within which total reflexion takes place, depends not only on the density of the reflecting prism, but also on the rarity of the medium adjacent to it, the extent of that range varies with the difference of the densities of the two media. When, therefore, the refractive power of one medium is known, that of any rarer medium may be learned, by examining at what angle a ray of light will be reflected from it.

For instance, when any object is laid under a prism of flint-glass, with air alone interposed, the internal angle of incidence at which the visual ray begins to be totally reflected, and at which the object ceases to be seen by refraction, is about 39° 10′; but when the object has been dipped in *water*, and brought into contact with the glass, it continues visible, by means of the higher refractive power of the water, as far as $57\frac{1}{2}^\circ$ of incidence. When any kind of *oil*, or any resinous cement, is interposed, this angle is still greater, according to the refractive power of the medium employed; and, by cements that refract more strongly than the glass, the object may be seen through the prism, at whatever angle of incidence it is viewed.

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* When quartz or topaz is used, the mean position of the refracted ray in the prism C, should coincide with the axis of the former, or one of the resultant axes of the latter.

In examining the refractive powers of fluids, or of fusible substances, the requisite contact is easily obtained; but, with solids, which can in few instances be made to touch to any great extent, this cannot be effected without the interposition of some fluid, or cement, of higher refractive power than the medium under examination. Since the surfaces of a stratum so interposed are parallel, it will not affect the total deviation of a ray passing through it, and may therefore be employed without risk of any error in consequence.

Thus, *resin*, or *oil of sassafras*, interposed between plate glass and any other prism, will not alter the result.

If, on the same prism, a piece of *selenite* and another of *plate-glass* be cemented near each other, their powers may be compared with the same accuracy as if they were both in absolute contact with it.

For such a mere comparison of any two bodies, a common triangular prism is best adapted; but, for the purpose of actual measurement of refractive powers, I have preferred the use of a square prism, because, with a very simple apparatus, it shows the sine of refractive power sought, without the need of any calculation.

Let A, Fig. 16. be a square or rectangular prism, to which any substance is applied at *b*, and let any ray of light parallel to *c b* be refracted through the prism, in the direction *b d e*.

Then, if *ef* and *e d* be taken proportional to the sines that represent the refractive powers of the prism and of air, *f g*, which is intercepted between *f* and the perpendicular *e g*, will be the corresponding sine to represent the refractive power of the medium *b*. For, since *e d g* (opposite to *e f*) is the angle of refraction, *e f g* (opposite to *e d*) must be equal to the angle of incidence *b d h*; and *e f* : *f g* : : *b d* : *d h* : : sine of *c b i* : sine of *h b d*.

All, therefore, that is requisite for determining the refractive power of *h*, is to find means of measuring the line *f g*. On this principle, the instrument in the annexed sketch (Fig. 17) is constructed. On a board *a b* is fixed a piece of flat deal *c d*, to which, by a hinge at *d*, is jointed a second piece *d e*, 10 inches long, carrying two plane sights at its extremities. At *e* is a second hinge, connecting *e f*, 15 83 inches long; and a third at the other extremity of *e f*, by which *f g* is connected with it. At *i* also is a hinge, uniting the radius *i g* to the middle of *e f*; and then, since *g* moves in a semicircle *e g f*, a line joining *e* and *g* would be perpendicular to *f g*.

The piece *c d* has a cavity in the middle of it, so that, when any substance is applied to the middle of the prism P, it may continue to rest horizontally on its extremities. When *e d* has been so elevated that the yellow rays in the fringe of colours (observable where perfect reflexion terminates) are seen through the sights, the point *g*, by means of a vernier which it carries, shows by inspection the length of the sine of refraction sought."

The ingenious instrument now described, was applied by Malus to measure the refractive powers of opaque bodies, by means of a prism, which exceeded them in refractive power. When they are placed in contact with one of the surfaces of the prism, the angle at which they cease to be seen by refraction is determined. Calling this angle $= \phi$; $m =$ the index of refraction of the prism, and m' that of the body to be determined, then Malus has shown, that,

For *opaque bodies*,

$$\text{Cos.}^2\,\phi = \frac{m^2 - m'^2}{2\,m^2}\,;\ \text{and}\ m'^2 = m^2 - 2\,n^2\,\text{Cos.}^2\,\phi$$

And for *transparent bodies*,

$$\text{Cos.}^2\,\phi = \frac{m^2 - m'^2}{m^2}\,;\ \text{and}\ m' = m\,\text{Sin.}\ \phi.$$

Dr. Young has remarked, that the index of refraction given by Dr. Wollaston's instrument is that which is appropriate to the extreme *red* rays. See *Phil. Trans.* 1802; Dr. Young's *Nat. Phil.* vol. ii. p. 298; *Memoires d'Arcueil*, tom. ii.; and Dr. Brewster's *Treatise on New Phil. Inst.* p. 240.

Sect. XVIII.—*Description of the Chromatic Thermometer.*

Differences of temperature have hitherto been measured by the expansions and contractions which they produce in solid, fluid, or gaseous bodies, and all the various thermometrical instruments that have been constructed, differ from each other only in the method by which these mechanical effects are rendered visible. The experiments contained in Art. II. p. 738, present us with an entirely new principle for the construction of a thermometer. We have there seen, that the tints polarised by a plate of glass, increase with the temperature by which they are produced, and therefore these tints may be used as a measure of the temperature, after the tints, corresponding to several points in the thermometrical scale, have been accurately ascertained.

An instrument of this kind, which Dr. Brewster has constructed, is represented in Fig. 18, where ABC is a series of 20 plates of glass, whose length AB is 3 2 inches, their breadth 1.2 inches, and their united thicknesses BC, 5.4 inches. A metallic vessel, DEFG, has its bottom formed of a thin layer of tin or lead, or any other suitable metal which can be poured in a fluid state upon the upper edges of the glass plates, so as to touch them in every part. This perfect contact may be obtained for higher temperatures, by grinding the bottom of the metallic vessel till it touches the edges of the glass in every point.

When a heated fluid is poured into the vessel DEFG, its heat will be instantly communicated to the edges of the plates, and when exposed to a polarised ray, subsequently analysed by reflexion from a transparent body, they will exhibit the coloured fringes at AB. Now, every tint in the scale of colours has a corresponding numerical value, which becomes a correct measure of the temperature of the fluid.

Instead of pouring the fluid into the vessel, we may remove the vessel altogether, and plunge the glass plates into the fluid. They must then be taken quickly out and suspended in a position where they are properly exposed to polarised light. The maximum tint which they develope at the centre, while cooling, is a measure of the temperature which they have acquired in the fluid.

In order to obtain some idea of the nature of the scale, Dr. Brewster made the following trials.—The heat of his hand, when applied to the edges of 20 plates of glass, produced instantly the fringes with the black spaces. With 12 plates he produced the yellow of the first order; and when one plate only was used, the black spaces, and the bluish white fringes were distinctly visible. A temperature of about 80°, that of the glass being 60°, when applied to 20 plates, polarised in the central fringe a *yellow* of the first order, which corresponds to a tint whose value is 4 in the scale of colours. Hence, one plate would have produced a tint corresponding to $\frac{4}{20}=0.20$ of the scale.

When one of the plates was placed upon a bar of red hot iron, just visible in day light, it polarised in the central fringe the commencement of the green of the second order, which corresponds to 9.35 in the scale.

Now the difference of temperature answering to 0.20 was 80°—60°=20°. Hence we have

As 0.20 : 9.35=20° : 935

the difference of temperature of the iron and the glass. The temperature of the iron is therefore 935°+60°=995°.

If we suppose the tints to be so indefinitely marked that the eye can only observe units of the scale of colours, we shall, even in this case, have a scale of 187 parts to measure the temperature of 935°—20°=915°, which is a scale having each of its divisions equal to nearly 4°.9. The tints, however, are much more definite than we have supposed; for, in the second order of colours, in which the observations may always be made, the eight different tints have the following measures.

Tints.	Values.
Violet	7.20
Indigo	8.18
Blue	9.00
Green	9.71
Yellow	10.40
Orange	11.11
Bright red	11.83
Scarlet	12.67

Now the difference of the values for violet and scarlet is 5.47, corresponding to *seven* different colours. Hence, upon the supposition that the eye can distinguish merely these separate colours, the accuracy of the scale is increased in the ratio of 5.47 to 7, that is, from 187 to 239, which gives 3°.83 for the value of each unit.

It is quite manifest, however, that we can distinguish at least three points in the development of each colour; and even if this could not be accomplished by the unassisted eye, it can readily be effected to a much greater extent, by crossing the fringe with a standard crystallized plate, and observing the degree of curvature which is produced in the fringes. This standard plate may be shaped like a wedge, so as to exhibit the variation of its tints to a great degree of minuteness. In a wedge of this kind, two inches long, and ground out of a crystallized parallelopiped, so as to have an angle of 8 degrees, the highest tint is between the *blue* and the *white* of the first order, corresponding to 2.20 of the scale, and the lowest tint is between the *black* and the *blue*, corresponding to about 0 8. We have therefore a scale of nearly two inches to measure a variation in the tints amounting to 2.20—0.80=1 40. The method of using the wedge or nonius is shown in Fig. 19. where AB is the wedge, exhibiting tints which vary in intensity from A to B. If we wish to ascertain the tints of a piece of crystallized glass CD, it must be held as in the figure, and moved from A to B. When it has the position CD, the intersectional figure is open horizontally, which shows that the tints of AB, at the point *m*, are higher than those of CD. In the position GH the figure is open vertically, and therefore the tints of the wedge at *o* are lower than those of the plate. But in the intermediate position EF, a dark cross is produced, which evinces the perfect equality between the tints of the wedge at *n* and those of the plate EF. In this manner all tints may be compared with each other, and referred to the scale of colours.

By forming wedges of crystallized glass in this way, we are enabled to observe the gradations by which the tints pass into each other, and to perform many experiments on the orders of colours, which would otherwise have been impracticable.

The sensibility of the preceding instrument depends on several other causes. 1*st*, On the intensity of the polarised pencil. 2*d*, On the transparency of the glass. And 3*d*, On the removal of all internal reflexions at the junction of the plates. In the instrument with 20 plates already mentioned, the glass has a green tinge, and the polarised light suffers no fewer than 40 reflexions before it reaches the eye. In order to remove these evils, the light should be polarised by reflexion from several of the thinnest and most colourless plates of glass that can be procured, so that each plate may polarise and reflect the light which is transmitted through the plate immediately above it. In this way we have obtained a light as brilliant as that which is reflected from silver. The internal reflexions may be removed by interposing a film of oil between each of the plates, so as to rise above that part of the plate where the tint is to be examined.

If the instrument is properly constructed, with these precautions, we have no hesitation in saying, that it will distinctly mark a difference of temperature equal to 1° of Fahrenheit's thermometer. See *Philosophical Transactions*, 1816, p. 108.

SECT. XIX.—*Description of the Optometer.*

The optometer is an ingenious instrument invented by Dr. Porterfield, but greatly improved by Dr. Thomas Young, for the purpose of determining the focal distance of the eye, and finding the kinds of glasses which are suitable to the various cases of long and short sighted vision. The following is Dr. Young's description of the improved instrument.

"Let an obstacle be interposed between a radiant point, Fig. 20. and any refracting surface or lens CD, and let this obstacle be perforated at two points A and B only. Let the refracted rays be intercepted by a plane, so as to form an image on it. Then it is evident, that when this plane EF passes through the focus of refracted rays, the image formed on it will be a single point. But if the plane be advanced forwards to GH, or removed backwards to IK, the small pencils, passing through the perforations, will no longer meet in a single point, but will fall on two distinct spots of the plane, G, H; I, K: and, in either case, form a double image of the object.

Let us now add two more radiating points, S and T, Fig. 21. the one nearer to the lens than the first point, the other more remote; and, when the plane, which receives the images, passes through the focus of rays coming from the first point, the images of the second and third points must both be double *s s*, *t t*; since the plane EF is without the focal distance of rays coming from the farthest point, and within that of rays coming from the nearest. Upon this principle, Dr. Porterfield's optometer was founded.

But, if the three points be supposed to be joined by a line, and this line to be somewhat inclined to the axis of the lens, each point of the line, except the first point, Fig. 22. will have a double image; and each pair of images, being contiguous to those of the neighbouring radiant points, will form with them two continued lines; and the images being more widely separated as the point which they represent is farther from the first radiant point, the lines $s\,t$, $s\,t$, will converge on each side towards r, the image of this point, and there will intersect each other.

The same happens when we look at any object through two pin holes, within the limits of the pupil. If the object be at the point of perfect vision, the image on the retina will be single; but, in every other case, the image being double, we shall appear to see a double object; and, if we look at a line pointed nearly to the eye, it will appear as two lines, crossing each other in the point of perfect vision. For this purpose, the holes may be converted into slits, which render the images nearly as distinct, at the same time that they admit more light. The number may be increased from two to four, or more, whenever particular investigations render it necessary.

This instrument has the advantage of showing the focal distance correctly, by inspection only, without sliding the object backwards and forwards, which is an operation liable to considerable uncertainty, especially as the focus of the eye may, in the mean time, be changed.

The optometer may be made of a slip of card paper, or of ivory, about eight inches in length, and one in breadth, divided longitudinally by a black line, which must not be too strong. The end of the card must be cut, as is shown in Fig. 23. in order that it may be turned up, and fixed in an inclined position by means of the shoulders; or a detached piece, nearly of this form, may be applied to the optometer, as it is here engraved, Fig. 24. A hole about half an inch square must be made in this part; and the sides so cut as to receive a slider of thick paper, with slits of different sizes, from a fortieth to a tenth of an inch in breadth, divided by spaces somewhat broader; so that each observer may choose that which best suits the aperture of his pupil. In order to adapt the instrument to the use of *presbyopic* or *long-sighted* eyes, the other end must be furnished with a lens of *four* inches focal length; and a scale must be made near the line on each side of it, divided from one end into inches, and from the other according to the table here calculated, by means of which, not only diverging, but also parallel and converging rays from the lens are referred to their virtual focus. If ivory be employed, its surface must be left without any polish, otherwise the regular reflexion of light will create confusion; and in this respect, paper is much preferable.

The instrument is easily applicable to the purpose of ascertaining the focal length of spectacles required for myopic or presbyopic eyes. Mr. Cary has been so good as to furnish me with the numbers and focal lengths of the glasses commonly made; and I have calculated the distances at which those numbers must be placed on the scale of the optometer, so that a presbyopic eye may be enabled to see at *eight* inches distance, by using the glasses of the focal length placed opposite to the nearest crossing of the lines; and a *myopic* or *short-sighted* eye, with parallel rays, by using the glasses indicated by the number that stands opposite their furthest crossing. It cannot be expected, that every person, on the first trial, will fix precisely upon that power which best suits the defect of his sight. Few can bring their eyes at pleasure to the state of full action, or of perfect relaxation; and a power two or three degrees lower than that which is thus ascertained, will be found sufficient for ordinary purposes. I have also added to the second table, such numbers as will point out the spectacles necessary for a presbyopic eye, to see at *twelve* and at *eighteen* inches respectively; the middle series will perhaps be the most proper for placing the numbers on the scale. The optometer should be applied to each eye; and, at the time of observing, the opposite eye should not be shut, but the instrument should be screened from its view. The place of intersection may be accurately ascertained, by means of an index sliding along the scale.

The optometer is represented in Figs 24. and 25.; and the manner in which the lines appear, in Fig. 26.

Table I. for Extending the Scale by a lens of 4 inches focus.

4	2 00	13	3.06	70	3.78	—40	4.44	—11	6.29
5	2.22	14	3.11	80	3.81	—35	4.51	—10	6 67
6	2.40	15	3.16	100	3.85	—30	4.62	— 9.5	6.90
7	2.55	20	3.33	200	3.92	—25	4 76	— 9.0	7.20
8	2.67	25	3.45	∞	4 00	—20	5.00	— 8 5	7.56
9	2.77	30	3 52	—200	4.08	—15	5.45	— 8.0	8.00
10	2.86	40	3.64	—100	4.17	—14	5.60		
11	2.93	50	3.70	—50	4.35	—13	5.78		
12	3.00	60	3 75	—45	4.39	—12	6.00		

Table II. For placing the Numbers indicating the focal length of convex glasses.

Foc.	VIII.	XII.	XVIII.
00	8.00	12 00	18.00
40	10.00	17 14	32.73
36	10.28	18.00	36.00
30	10.91	20.00	45.00
28	11.20	21.00	50.40
26	11.56	22 29	58.50
24	12 00	24.00	72.00
22	12 77	26.40	99.00
20	13.33	30.00	180.00
18	14.40	36.00	∞
16	16.00	48.00	—144.00
14	18.67	84.00	— 63.00
12	24.00	∞	— 36 00
11	29.33	—132.00	— 28.29
10	40.00	— 60.00	— 22.50
9	72.00	— 36.00	— 18.00
8	∞	— 24.00	— 14.40
7	—56.00	— 16.80	— 11.45
6	—24.00	— 12.00	— 9.00
5	—13.33	— 8 57	— 5 92
4 5	—10.29	— 7.20	— 6.00
4.0	— 8.00	— 6.00	— 5.14
3.5	— 6.22	— 4.94	— 4.34
3.0	— 4.80	— 4.00	— 3.60

Table III. For Concave Glasses.

Number.	Focus.	Number.	Focus.	Number.	Focus.
1	24	8	7	15	2.75
2	18	9	6	16	2.50
3	16	10	5	17	2.25
4	12	11	4.5	18	2.00
5	10	12	4.0	19	1.75
6	9	13	3.5	20	1.50
7	8	14	3.00		

See *Edinburgh Medical Essays*, vol. iv. p. 185; and Dr. Thomas Young's *Lectures on Nat. Phil.* vol. ii. p. 575; or *Phil. Trans.* 1801.

CHAP. II.

ON THE METHOD OF FORMING THE LENSES AND SPECULA OF REFRACTING AND REFLECTING TELESCOPES, &c.

SECT. I.—*On the Method of Grinding and Polishing Lenses.*

Having fixed upon the proper aperture and focal distance of the lens, take a piece of sheet copper, and strike a fine arch upon its surface, with a radius equal to half that distance, if it is to be plano-convex, and let the length of this arch be a little greater than the given aperture. Remove with a file that part of the copper which is without the circular arch, and a *convex gage* will be formed. Strike another arch with the same radius, and having removed that part of the copper which is within it, a *concave gage* will be obtained. If the sheet copper is thin, the steel point which strikes the arch may be made to cut it through by successive repetitions of the stroke.* Prepare two circular plates of brass, about one-tenth of an inch thick, and half an inch greater in diameter than the breadth of the lens, and solder them upon a cylinder of lead of the same diameter, and about an inch high. These tools are then to be fixed upon a turning lathe, and one of them turned into a portion of a *concave* sphere, so as to suit the *convex* gage; and the other into a portion of a *convex* sphere, so as to answer the *concave* gage. After the surfaces of the brass plates are turned as accurately as possible, they must be ground upon one another alternately with flour emery, and when the two surfaces exactly coincide, the grinding tools will be ready for use.

Procure a piece of glass of a straw colour, whose dispersive power is as small as possible, if the lens is not for achromatic instruments, and whose surfaces are parallel; and by means of a pair of large scissars or pincers, cut it into a circular shape, so that its diameter may be a little greater than the required aperture of the lens. When the roughness is removed from its edges by a common grindstone,† it is to be fixed with black pitch to a wooden handle of a smaller diameter than the glass, and about an inch high, so that the centre of the handle may exactly coincide with the centre of the glass.

The glass being thus prepared, it is then to be ground with fine emery upon the concave tool, if it is to be convex, and upon the convex tool if it is to be concave. To avoid circumlocution, we shall suppose that the lens is to be *convex*. The concave tool, therefore, which is to be used, must be firmly fixed to a table or bench, and the glass wrought upon it with circular strokes, so that its centre may never go beyond the edges of the tool. For every six circular strokes the glass should receive two or three cross ones along the diameter of the tool, and in different directions. When the glass has received its proper shape, and touches the tool in every point of its surface, which may be easily known by inspection, the emery is to be washed away, and finer kinds‡ successively substituted in its room, till, by the same alternation of circular and transverse strokes, all the scratches and asperities are removed from its surface. After the finest emery has been used, the roughness which remains may be taken away, and a slight polish superinduced by grinding the glass with pounded pumice-stone, in the same manner as before. While the operation of grinding is going on, the convex tool should, at the end of every five minutes, be wrought upon the concave one for a few seconds, in order to preserve the same curvature in the tools and the glass. When one side is finished off with the pumice-stone, the lens must be separated from its handle by inserting the point of a knife between it and the pitch, and giving it a gentle stroke. The pitch which remains upon the glass may be removed by rubbing it with a little oil, or spirits of wine; and after the ground side of the glass is fixed upon the handle, the other surface is to be wrought and finished in the very same manner.

When the glass is thus brought into its proper form, the next and the most difficult part of the operation is to give it a fine polish. The best, though not the simplest way of doing this, is to cover the concave tool with a layer of pitch, hardened by the addition of a little rosin to the thickness of one fifteenth of an inch. Then, having taken a piece of thin writing paper, press it upon the surface of the pitch with the convex tool, and pull the paper quickly from the pitch before it has adhered to it; and if the surface of the pitch is marked everywhere with the lines of the paper, it will be truly spherical, having coincided exactly with the surface of the convex tool. If any paper remains on the surface of the pitch, it may be removed by soap and water; and if the marks of the paper should not appear on every part of it, the operation must be repeated till the polisher, or bed of pitch, is accurately spherical. The glass is then to be wrought on the polisher by circular and cross strokes, with the oxide of tin, called the *flowers of putty* in the shops, or with the *red oxide of iron*, otherwise called *colcothar of vitriol*, till it has received on both sides a complete polish.* The polishing will advance slowly at first, but will proceed rapidly when the polisher becomes warm with the friction. When it is nearly finished, no more putty or water should be put upon the polisher, which should be kept warm by breathing upon it; and if the glass moves with difficulty from its adhesion to the tool, it should be quickly removed, lest it spoil the surface of the pitch. When any particles of dust or pitch insinuate themselves between the glass and the polisher, (which may be easily known from the very unpleasant manner of working,) they should be carefully removed, by washing both the polisher and the glass, otherwise the lens will be scratched, and the bed of pitch materially injured.

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* When the arch to be struck is part of a circle of a very great radius, it may be projected trigonometrically in the way shown by Huygens, in his *Comment. de Formandis, Poliendisque Vitris, &c.* at the end of his *Dioptrica*, p. 267. See also Smith's *Optics*, vol. ii. p. 283.

† When the focal distance of the lens is to be short, the surface of the piece of glass should be ground upon a common grindstone, so as to suit the gage as nearly as possible; and the plates of brass, before they are soldered on the lead, should be hammered as truly as they can be done into their proper form. By this means much labour will be saved both in turning and grinding.

‡ Emery of different degrees of fineness may be made in the following manner. Take five or six clean vessels, and having filled one of them with water, put into it a considerable quantity of flour emery. Stir it well with a piece of wood, and after standing for five seconds pour the water into the second vessel. After it has stood about twelve seconds, pour it out of this into a third vessel, and so on with the rest; and at the bottom of each vessel will be found emery of different degrees of fineness, the coarsest being in the first vessel, and the finest in the last.

The operation of polishing may also be performed by covering the layer of pitch with a piece of cloth, and giving it a spherical form by pressing it with the convex tool when the pitch is warm. The glass is wrought, as formerly, upon the surface of the cloth, with putty or colcothar of vitriol, till a sufficient polish is induced. In this method the operation is slower, and the polish less perfect; though it is best fitted for those who have but little experience, and would therefore be apt to injure the figure of the lens by polishing it on a bed of pitch.

In this manner the small lenses of simple and compound microscopes, the eye-glasses and the object-glasses of telescopes, are to be ground. In grinding concave lenses, Mr. Imison employs leaden wheels with the same radius as the curvature of the lens, and with their circumferences of the same convexity, as the lens is to be concave. These spherical zones are fixed upon a turning lathe, and the lens, which is held steadily in the hand, is ground upon them with emery, while they are revolving on the spindle of the lathe. In the same way convex lenses may be ground and polished, by fixing the concave tool upon the lathe; but these methods, however simple and expeditious they may be, should never be adopted for forming the lenses of optical instruments, where an accurate spherical figure is indispensable. It is by the hand alone that we can perform with accuracy those circular and transverse strokes, the proper union of which is essential to the production of a spherical surface.

Sect. II. *On the Method of Casting, Grinding, and Polishing the Specula of Reflecting Telescopes.*

The specula of reflecting telescopes are generally composed of 32 parts of copper, and 15 of grain tin, with the addition of two parts of arsenic, to render the composition more white and compact. Sir Isaac Newton used 6 parts of copper, 2 of tin, one of arsenic, which, though it formed a compact metal, is yellow when polished. Mr. Mudge employed 32 parts of copper, and 14½ of tin, which also makes a good metal, though still too yellow. The Reverend Mr. Edwards found, from a variety of experiments, that if one part of brass, and one of silver,† be added to the composition first mentioned, viz. 32 of copper, 15 of grain tin, and only one part of arsenic used, a most excellent metal will be obtained, which is the whitest, hardest, and most reflective, that he ever met with. The superiority of this composition, indeed, has been completely evinced by the excellence of Mr. Edwards' telescopes, which excel other reflectors in brightness and distinctness, and show objects in their natural colours.

The sand which is most proper for casting specula, is a fine sand, with just as much loam or clay naturally mixed with it, as will render it tenacious enough to adhere when properly moistened. If there is too much clay, the sand will blow the metal in different directions, to the great risk of the operator; and if there is too little clay, the sand will not remain in the flask, or take a proper impression from the pattern or model. The sand should be wetted as little as possible, and well beaten, though not too hard. The flasks should be at least too inches wider than the metal intended to be cast, for when the thickness of the sand is too small, it will instantly become dry when the hot fluid metal is poured into it, and consequently will contract, and allow the fluid metal to run out of the flasks. The pattern should be made of brass or pewter, and should be a little larger and thicker than the speculum to be cast from it.

After the flasks of sand‡ are prepared, and a mould made for the metal by means of the pattern, so that its face may be downwards, and a few small holes left in the sand at its back, for the free egress of the included air;—melt the copper in a crucible by itself, and when it is reduced to a fluid state, fuse the tin in a separate crucible, and having mixed it with the melted copper, by stirring them together with a wooden spatula, pour the whole into a large quantity of cold water, which will divide the mass into an infinite number of small particles. Melt the proportional quantity of silver and brass in a small crucible by itself, and when the composition of copper and tin is put the second time into the crucible, add also the lump of brass and silver previously melted, and when the whole is fluid, put in the proportional quantity of arsenic.§ and then pour the whole off into the flasks, after the scoria has been removed, and a little powdered rosin thrown in‖. As soon as the metal is become solid, remove it from the sand into some hot ashes or coals, for the purpose of annealing it, and let it remain among them till they are completely cold. The ingate is then to be taken from the metal by means of a file; and the surface of the speculum must be ground upon a common grindstone, till all the imperfections and asperities are taken away. Mr. Edwards' composition will always break or tear up within the finest emery; but the effect thus produced will always be taken out by the bed of hones, and when the common blue hone is employed, a small quantity of water must be used at a time.

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* As colcothar of vitriol is obtained by the decomposition of martial vitriol, it sometimes retains a portion of this salt When this portion of martial vitriol is decomposed by dissolution in water, the yellow ochre which results penetrates the glass, forms an incrustation upon its surface, and gives it a dull and yellowish tinge, which is communicated to the image which it forms.

† The *silver* in this composition makes the metal much whiter; the small proportion of *brass* renders it more bright, and not so excessively brittle, and the *arsenic* makes the metal much more solid and compact, and consequently much more free of pores.

‡ The finest sand which we have met with in this country is to be found at Roxburgh castle, in the neighbourhood of Kelso.

§ The operator must take care to retain his breath till the noxious fumes of the arsenic are dissipated.

‖ Mr Edwards recommends *coak*, or common coal charred, as the best fuel, in consequence of its giving the purest and the most constant heat.

When the metal is cast, and prepared by the common grindstone for receiving its proper figure, the gages and grinding tools are to be formed in the same manner as for convex lenses, with this difference only, that the radius of the gages must always be double the focal length of the speculum. In addition to the convex and concave brass tools, which should be only a little broader than the metal itself, a convex elliptical tool of lead and tin should also be formed with the same radius, so that its transverse may be to its conjugate diameter as 10 to 9, the latter being exactly equal to the diameter of the metal. On this tool the speculum is to be ground with flour emery, in the same manner as lenses, with circular and cross strokes alternately, till its surface is freed from every imperfection, and ground to a spherical figure. It is then to be wrought with great circumspection, on the convex brass tool, with emery of different degrees of fineness, the concave tool being sometimes ground upon the convex one, to keep them all of the same radius; and when every scratch and appearance of roughness is removed from its surface, it will be fit for receiving the final polish. Before the speculum is brought to the polisher, it has been the practice to smooth it on a bed of hones, or a convex tool made of common blue hones. This additional tool, indeed, is absolutely necessary, when silver and brass enter into the composition of the metal, in order to remove that roughness which will always remain after the finest emery has been used; but when these metals are not ingredients in the speculum, there is no occasion for the bed of hones. Without the intervention of this tool we have finished several specula, and given them as exquisite a lustre as they could possibly have received. Mr. Edwards does not use any brass tools in his process, but transfers the metal from the elliptical leaden tool to the bed of hones. By this means the operation is simplified, but we doubt much if it is, in the least degree, improved. As a bed of hones is more apt to change its form than a tool of brass, it is certainly of great consequence that the speculum should have as true a figure as possible before it is brought to the hones; and we are persuaded, from experience, that this figure may be better communicated on a brass tool, which can always be kept at the same curvature by its corresponding tool, than on an elliptical block of lead. We are certain, however, that when the speculum is required to be of a determinate focal length, this length will be obtained more precisely with the brass tools than without them. But Mr. Edwards has observed that these tools are not only unnecessary, but "really detrimental." That Mr. Edwards found them unnecessary, we cannot doubt, from the excellence of the specula which he formed without their assistance; but it seems inconceivable how the brass tools can be in the least degree detrimental. If the mirror is ground upon 20 different tools before it is brought to the bed of hones, it will receive from the last of these tools a certain figure, which it would have received, even if it had not been ground on any of the rest; and it cannot be questioned, that a metal wrought upon a pair of brass tools is equally, if not more, fit for the bed of hones, than if it had been ground merely on a tool of lead.

When the metal is ready for polishing, the elliptical leaden tool is to be covered with black pitch, about one-twentieth of an inch thick, and the polisher formed in the same way as in the case of lenses, either with the concave brass tool, or with the metal itself. The colcothar of vitriol should then be triturated between two surfaces of glass, and a considerable quantity of it applied at first to the surface of the polisher. The speculum is then to be wrought in the usual way upon the polishing tool, till it has received a brilliant lustre, taking care to use no more of the colcothar, if it can be avoided, and only a small additional quantity of it, if it should be found necessary. When the metal moves stiffly on the polisher and the colcothar assumes a dark muddy hue, the polish advances with great rapidity. The tool will then grow warm, and would probably stick to the speculum, if its motion were discontinued for a moment. At this stage of the process, therefore, we must proceed with great caution, breathing continually on the polisher, till the friction is so great as to retard the motion of the speculum. When this happens the metal is to be slipped off the tool at one side, cleaned with soft leather, and placed in a tube for the purpose of trying its performance; and if the polishing has been conducted with care, it will be found to have a true *parabolic* figure.

In polishing the small speculum for his Newtonian reflectors, Sir W. Herschel always employed two or more tools considerably larger than the speculum to be polished; but he did not use them till after the speculum was made nearly flat with emery upon a small tool of lead. These tools, or beds of hones, should not be less than six inches in diameter, and the figure of the tools is not considered as completed, till the speculum can be first highly finished upon one of them, and afterwards be applied to another, without experiencing any change of figure. The last half dozen strokes should be performed in the direction of the longer axis of the ellipse. When the speculum is thus brought to a perfect figure, it must be polished upon a pitch polisher of a circular form, whose diameter is about *one-tenth* part greater than the longer or transverse axis of the speculum.

For additional information on the subject of grinding and polishing lenses and specula, the reader is referred to Huygens' *Dioptrica*, p. 267; Smith's *Optics*, vol. ii.; Mudge, *Phil. Trans.* 1777, vol. lxvii. p. 296; Rev. Mr. Edwards, in the *Nautical Almanack* for 1787; and Ferguson's *Lectures*, *Appendix*, vol. ii.

For farther information on the subject of optical instruments, &c. see the articles ACCIDENTAL COLOURS, ACHROMATIC TELESCOPES, ANAMORPHOSIS, BURNING INSTRUMENTS, CAMERA LUCIDA, CYANOMETER, DIAPHANOMETER, HEAT, HELIOSTATE, MICROMETER, and MICROSCOPE.

ORDNANCE.

This term is generally intended to designate all the larger species of warlike fire-arms, used both for land and sea service, and is thereby more comprehensive in its signification than the term artillery, which is applied only to the former.

There is some uncertainty as to the date when these machines were first introduced into the military system of European powers, for the attack and defence of strong places, and in the field; but, it is highly probable, that it was not long after the invention of gunpowder. Father Daniel, in his life of Philip de Valois, produces proofs from the records of the chamber of accounts at Paris, that cannon were used in the year 1338, and Froissart and some other French historians state them to have been employed still earlier. In the lists of aid raised for the redemption of king John of France, in 1368, mention is made of an officer in the French army, under the denomination of *master of the king's cannon*, and of his providing four large cannon for the garrison of Harfleur. The English unquestionably employed these arms as early as 1346, at the celebrated battle of Cressy, and from the statement of the French historians, this appears to have been the first instance in which they were used in the field, and they are said to have contributed greatly to the success of that day. The English also made use of them the following year at the siege of Calais; and in 1350, they are said to have been employed on ship-board, in the Baltic, an assertion, of the truth of which, however, we must be allowed to entertain some doubts. Some of the oldest cannon of known origin, preserved as curiosities in our arsenals, &c. seem not to bear an earlier date than about the middle of the sixteenth century; but there are others, obviously of an anterior construction, of which it is impossible to trace the history. At this early time, the forms and means of removing, adjusting, &c. were so exceedingly rude and uncultivated, that the application of guns or instruments of attack and defence must have been attended with great labour and uncertainty. Although we have some accounts of enormous cannon being bored as early as the year 1400, yet it seems unquestionable that some, after that date, were formed of wrought iron bars, fitted together and hooped with rings. (See Plate CCCCXLIII. Fig. 1) which is an exact representation of one of these guns, in the arsenal at Woolwich. In general, after the art of boring had been applied to the purpose of forming cannon, it seems to have been an object of emulation amongst the different European powers, to produce the largest possible pieces; for in that early period of the artillery art, we find the guns large, and especially long, beyond all due proportion, and far beyond the necessity of the case; of mortars in particular, we find dimensions stated which appear wholly incredible. Thus, Mahomet II. is said to have employed against the walls of Constantinople, in 1453, a mortar capable of throwing a ball, or at least of a calibre equal to a ball, of 1200 lbs. which would require the diameter of the bore to be nearly 24 inches.

Whether this statement be correct or not, there is no doubt that the first cannon and mortar were exceedingly unwieldy and unmanageable, and that they could only be discharged three or four times in a day. Guicciardin informs us, in the first book of his History, that so great a portion of time intervened between the different chargings and dischargings, that the besieged had sufficient time to repair, at their leisure, the breaches made in the walls by the enormous stones that were thrown upon them. Although the use of these extraordinary pieces of ordnance was not of long duration, yet, even in the seventeenth century, the cannon were still much larger and longer than at present, and great pains were taken to ornament them, sometimes with a certain degree of elegance, but frequently with various unmeaning symbols, figures, and mottos; they had also certain names given to them, as we still give to our ships, as, the Thunderer, the Terrible, &c.

Thus, Louis XII. in 1503, had twelve brass cannon cast of an extraordinary size, which he named after the twelve peers of France. The Spaniards and Portuguese named theirs after their saints. The Emperor Charles V. when he went against Tunis, had twelve cannon founded, which he called the twelve apostles. At Milan, there is a seventy pounder, called the Pimontelli, and one at Bois le Duc, called the Devil; at Dover, there is a sixty pounder, named Queen Anne's pocket pistol; and an eighty pounder in the Tower of London, brought from Edinburgh, called Mount's Meg. There is also an eighty pounder in the arsenal at Berlin, named the Thunderer; and one of the same calibre at Malaga, called the Terrible. There are likewise two curious sixty pounders at Bremen, designated the *messengers of bad news;* and also a seventy pounder in the castle of St. Angelo, at Rome, made of the nails which fastened the copper plates that covered the ancient Pantheon.

The largest cast gun existing is a brass one at Beijapoor: it is called "Malick é Meidān," (Lord of the Plain.) It was cast in commemoration of the capture of Beijapoor, by the Emperor Alum Geer, in Anno Hijrez, 1097, A. D. 1685.) It is ornamented with Persian and Arabic inscriptions in relief.

Extreme length,	14 feet,	1 inch.	Diam at muzzle-ring	4 f.	8 in.
Diam. at breech,	4	10½	Diam. of bore,	2	4

It is supposed to be intended for stone balls. An iron shot of proper size would weigh about 2600 lbs. It has been fired only once, on which occasion the bastion it is mounted on was damaged, and the stone shot knocked down part of a mosque which it struck.

Of late years, the object of the different powers of Europe has been to reduce the weight and magnitude of their cannon, and to increase the number of them. And to such a pitch was the latter carried by the English in the last war, that, notwithstanding the immense supplies that we had furnished to our own armies, and to our allies, there were in the arsenal at Woolwich, at the time the Emperor Alexander visited it, nearly forty thousand pieces of ordnance, including only cannon, carronades, howitzers, and mortars.

Explanation of the several parts of a Gun.

The following are the technical terms applied to the different parts of a gun, and which are necessary to be known before we attempt to illustrate the practical construction of these pieces of ordnance. Referring to Fig. 3. Plate CCCCXLIII.

AB is called the length of the gun.
AC the first reinforce.
CD the second reinforce.
DE the chase.
EB the muzzle.
FA the cascable.
GH the bore.
RK the axis of the piece.
G the bottom of the bore.
II the trunnions.
KK the dolphins or handle.
LL the vent field.
M the pan.
N the vent.
O the swell of the muzzle.
PG the breech.
S the button.

a b the button ring.
c d the neck of the button.
e f the neck fillet.
g g the breech ogee.
h h the base ring.
i i the base ring ogee.
k k vent field astragals and fillets.
l l' the first reinforce ring.
m m' second reinforce ring and ogee.
n n' muzzle astragal and fillets.
o o' muzzle mouldings.
s s' shoulder of trunnion.
t u diameter of the bore or calibre.
p q groove of the tangent scale.

These terms apply to every species of ordnance in which the parts enter, and may therefore be considered as a set of general definitions. We proceed now to the construction of brass cannon.

Construction of a Light Six Pounder Brass Gun.

According to the present principle of construction, the light six pounder is 5 feet in length, and weighs about 6 cwt. The calibre, which exceeds the diameter of the ball by one tenth, is 3.668 inches, and this calibre is divided into sixteen equal parts, which constitute the unit of measure in the several minor parts: but, in the general dimensions, the unit is taken one 18th of the length.

Having divided a line intended to represent the length of the gun into 18 equal parts, let a line be drawn parallel to it, to represent the axis of the piece, and from the fifth division of the scale, draw a line perpendicular to the axis, as 5 C, Fig. 2. which limits the length of the first reinforce AC. The length of the second reinforce CD, is equal to three eighteenths, plus one calibre; that is, the centre of the trunnions being determined by the line 8 Q, drawn parallel to the axis of the gun from the division 8. on the scale line, *e* D is taken equal to one calibre, making *c* D equal to three eighteenths and one calibre; the remainder of the length is for the chase and muzzle.

The thickness EF of the breech is 11 parts, and GH at the face 4 parts. The lines EH, PS, being drawn, will determine the external surface of the chase. To determine the external surface of the first reinforce, the line FI is drawn parallel to the axis of the piece, KI is bisected in X, and FX is drawn, which is the external surface required. In the same way the external surface of the second reinforce is found, viz. draw XL parallel to the axis, and bisect LM in N′, and join XN′.

The axis ON of the trunnions is perpendicular to that of the gun, and placed, as we have stated above, eight eighteenths of the length of the piece from the breech, and their centre *a* is placed one eighteenth of their diameter *a b*, above the lower surface of the base, which diameter is $\frac{13}{16}$ths of a calibre; their length is $\frac{15}{16}$ of a calibre, the projection of the second reinforce ring being added to this length. The breadth *b e* of the shoulder is one tenth of the diameter *a b*, and the projection which is equal to that of the second reinforce ring, is made parallel to the axis of the piece.

The bottom of the piece is described from the three centres *g h l*, the first of which is distant from it one calibre. The others are determined by the intersections of *f g*, and *m l*, $f i, = f e, = e g''$, F *q p* P, of the breech, is concentric with *o g p*, and is described with the radius *g* F.

The breadth A *l* of the base ring is $\frac{1}{18}$ of AC, and the width of the first reinforce ring is $\frac{3}{4}$ths of the base ring; the breadth of the second reinforce ring is also $\frac{3}{4}$ths of the base ring, and the reinforce ogee is $\frac{3}{4}$ths of its ring. The astragals, their fillets included, are likewise $\frac{3}{4}$ths of the base ring, and each fillet is half its astragal.

The projections of the first and second reinforce rings, as well as that of the fillets, are one half of the breadth of the fillet, excepting the fillet at the muzzle, the projection of which is equal to the whole breadth of the fillet. The projection of the base ring is $\frac{2}{16}$ths of a calibre, and its surface is determined by a line touching the projections of the first and second reinforce rings.

The vent field is found by placing the centre of the vent field astragal one calibre from the ogee; the pan extends from the base ring to the fillet of the vent field astragal; its breadth is two inches, and its projection is determined by a tangent to the swell of the ogee in a direction parallel to the vent field.

The vent is $\frac{2}{16}$ of an inch in diameter, and takes its direction from a point *n* in the axis, one quarter of a calibre from the bottom of the bore to the point *r*, where a line drawn from the bottom of the bore perpendicular to the axis, meets the surface of the pan.

Muzzle.

The length of the muzzle *k f* is one fifth of the length of the chase DB, the neck is one third B *f*, the centre *e* of the swell is distant one sixth of B *f* from the face HS; and the breadth B *n* of the fillet and astragal is two-thirds of B *e*.

The diameter of the swell is 33 parts, and so proportioned to that of the base ring, as to give a dispart of 1°; it is described with a radius $r s = \frac{1}{3}$ B *e*, and the hollow at *m* is described with a radius $= 5$ *c*, *d*; *c d* being the thickness of the gun at the neck. Lastly, the diameter of the fillet is determinnd by a line drawn through the centre of the swell, parallel to the axis of the piece. See Plate CCCCXLIII. Fig. 4.

Cascable.

The length *k m* of the cascable is one calibre and six parts, the diameter *p q* of the last fillet is one calibre and two parts. The distance of the last fillet to the centre of the button is $10\frac{1}{2}$ parts, and the button is described with a radius of $6\frac{1}{2}$ parts, from the centre *l′*. From the same centre describe an arc with a radius $= 11\frac{1}{2}$ parts, and another from *p* with a radius of five parts; then from their intersection *o′*, and *o p* as a radius, describe the arc *p h*, which will determine the neck. The ogee *h e i* is determined by means of the isosceles triangles *e f i*, *e g h*, the sides *e f*, *f i*, *e g*, *g h*, being each equal to $\frac{11}{12}$ths of *i h*; $a b = 10$ parts $c d = a b = 2\frac{1}{4}$ parts, $a i = \frac{1}{14} a b$, and $n y = \frac{1}{3} c d$. See Fig. 5.

General Construction of Brass Guns.

The preceding construction being understood, there will be no difficulty in comprehending the following general principle of construction, although we shall not enter so minutely into particulars.

In general, modern guns are proportioned in length to their calibres, being in one class seventeen, and in the other, thirteen calibres. The guns of seventeen calibres are 12, 9, 6, and 3 pounders; those of thirteen calibres are 24, 18, and 12 pounders; besides which, the 6, 3, and 1 pounders are, as we have seen in the preceding construction, in some instances, of determinate lengths, without reference to the number of calibres. The weights and lengths of the first class are

		Feet.	Inches.	Weight.
17 Calibres.	12 pdrs. length	6	6.660	18 cwt.
	9 do.	5	11.400	$13\frac{1}{2}$
	6 med. do.	5	2.356	9
	3 do.	4	1 521	$4\frac{1}{2}$
13 Calibres.	24 do.	6	3 669	24
	18 do.	5	8.796	18
	12 do.	5	0.009	12
Not proportioned by calibre.	6 do.	5	0.000	6
	3 do.	6	0.000	6
	1 do.	5	0.000	$2\frac{1}{2}$

General Dimensions. Fig. 6.

	Breech.	Muzzle.
12, 9, 6, and 3 pdrs. of 17 cal.	$AY = CI = \frac{7}{8}$ cal.	$KL = \frac{5}{8}$ cal.
24, 18, and 12 pounders, of 13 cal.	$= \frac{3}{4}$	$= \frac{3}{8}$
6 pdrs. light, length 5 feet 6 inches	$= \frac{11}{16}$	$= \frac{4}{8}$
3 do. 6 feet 0 inches	$= \frac{7}{8}$	$= \frac{3}{8}$
1 do. 5 feet 0 inches	$= \frac{7}{8}$	$= \frac{1}{8}$

The fractions expressing parts of a calibre.

The diameter of the swell at the muzzle is so proportioned in all to the respective base rings, as to give a dispart of a degree.

The distance CD in the guns of 13 calibre is $\frac{3}{4}$ calibre, in the others one calibre.

The diameter of trunnions is $\frac{1}{3}$ GH, or of base ring, and the length is equal to the diameter. Centre of trunnions to centre of second reinforce ring $\frac{3}{4}$, or 1 calibre, as above stated. Breadth of reinforce rings $= \frac{3}{4}$ of base ring.

Dimensions of the Cascable.

In those of

	$mn =$	$op =$	$qn =$	$ar =$
17 cal.	1 calibre	$\frac{9}{16}$	$\frac{9}{32}$	$\frac{6}{16}$
13 do.	1	$\frac{9}{16}$	$\frac{9}{32}$	$\frac{6}{16}$
6 pdrs. $5\frac{1}{2}$ feet	$\frac{9}{8}$	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{13}{32}$
3 do. 6 feet	1	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$
1 do. 5 feet	1	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{2}$

The other particulars of the general construction may be stated as follows:

$eB = \frac{1}{9}$ of fB.
$ic = \frac{1}{3}$ of fB.
$bf = \frac{3}{4}$ of base ring.
$fB = \frac{2}{7}$ of BD.
$mD = \frac{5}{4}$ of base ring.
$Dn = \frac{3}{4}$ of mD or $\frac{9}{16}$ of base ring.
$CD = \frac{3}{4}$ of a calibre, or 1 calibre.
$AD =$ eight eighteenths of the length of the gun plus one calibre.
$AB' =$ five eighteenths of the length.
$AC =$ eight eighteenths.
$B'q = \frac{3}{4}$ of base ring.
$rs = \frac{3}{4}$ of base ring.
$Yn = \frac{1}{4}$ of calibre.
$gY = 1$ calibre.
$tv = \frac{3}{4}$ of base ring.
$At =$ one eighteenth of $AC =$ base ring
$Aa = 1$ calibre.
$BI = AH$
X bisects KI, and N bisects ML.

It will be understood that these constructions apply only to the guns at this time making, or lately made, for the British service; but we employ a variety of other pieces, which differ very considerably in their lengths and other dimensions; the principal of which are given in the following table.

Table showing the Length, Weight, and other particulars of English Brass Guns.

	Nature of the Guns.	Calibres.	Length in Feet.		Weight.		
			ft.	*in.*	*cwt.*	*qr.*	*lbs.*
42	Pounders -	16.244	9	6	66	0	0
32	do.	18.721	10	0	55	2	0
24	Heavy -	19.574	9	6	53	0	9
	Medium -	16.483	8	0	41	3	2
	Light - -	10.302	5	0	16	3	13
	New do. -	13.000	6	3	24	0	0
18	Pounders -	13.000	5	9	18	0	0
12	Heavy - -	24.659	9	0	31	2	8
	Gen. Desagulier's	19.468	7	6	22	1	21
	Medium, old	16.872	6	6	21	3	0
	*Medium, new	16 872	6	6	18	0	0
	Light - -	12.978	5	0	8	3	4
	*Light, new -	13.000	5	0	12	0	0
9	Pounder -	17.000	5	$11\frac{4}{16}$	13	2	0
6	Heavy - -	26 112	8	0	19	1	6
	*Desagulier's med.	2 876	7	0	12	0	24
	*Medium, new	18.500	6	0	8	3	27
	*Medium reduced	17.000	5	6	8	0	22
	Gen. Belford's	16.342	5	0	5	2	21
	Light, common	14.706	4	6	5	0	18
3	Heavy - -	28 836	7	0	11	3	19
	*Gen. Desagulier's	14.717	6	0	6	0	0
	*Light common	14 418	3	6	2	2	27
	Light infantry	12.358	3	0	1	3	16
	Gen. Pattison's	12.358	3	0	1	2	19
1	Pdr. ammuzethe	29.7	5	0	2	2	12
	do. - -	15 6	6	0	3	0	11
	do. - -	11.5	7	0	3	1	12

The guns marked * are the only ones now used in general service.

The iron guns in the English service are still more variable in their construction, dimensions, weight, &c.

than those of brass, as will be seen by the following Table.

Table showing the particular Dimensions, Weight, &c. of Naval and Battering Ordnance employed in the British Service.

Weight of ball.		Weight of cannon.		Ratio of weight of ball to weight of gun.	Angle of dispart.	Length of piece.	Length of bore.	Bore in terms of the calibre
		cwt.	qr.			feet.	inches.	
42*		67	0	178.6	1½	10	112	16.75
32	1	55	0	192.5	1½	9½	107.2	17.5
	2	49	3	174.1	2	8	89.22	14.6
24	1	50	0	233	1½	9½	107.41	19.3
	2	47	2	221.7	1½	9	101.45	18.3
	3	44	2	203	1½	8	89.5	16.1
	4	40	0	186.6	2	7½	83 42	15.0
	5	40	0	186 6	5	7½	83.42	15,1
	6	33	0	154	2¼	6½	71.79	12.9
	7	31	0	144.7	2¼	6	57.05 8.82	10.3 1.6
18	1	42	0	261.3	1½	9	101 75	20.0
	2	37	2	233.3	1½	8	89.74	17.8
	3	24	0	168	2¼	6	66.05	13.1
12	1	34	0	327.3	1	9	102.23	23.3
	2	33	0	308	1½	8½	96.221	21.9
	3	29	2	275	1½	7½	84.25	19.1
9	1	31	2	392	1¼	9	102.487	25.6.
	2	28	2	354.6	1½	8½	96 48	24.1
	3	26	0	323.5	1½	7½	84.425	21.2
	4	25	0	311.1	1½	7	78.48	19 6
6	1	23	0	322	1½	8½	96.957	27.8
	2	22	0	308	1½	8	90.956	26 0
	3	21	0	294	1½	7½	84.96	24.3
	4	20	0	280	1½	7	78,952	22.5
	5	18	0	252	1½	6½	72,96	20.9
	6	17	0	238	1½	6	66 97	19.4

Of Carronades.

Carronades† were first introduced into the English service by General Robert Melville, and were, in the first instance, of one calibre only, (68 pounds.) and denominated ***smashers*** ; but they have since received the above name from that of the celebrated foundery of Carron in Scotland, where they were first cast, under the able directions of Charles Gascoine, Esq. at that time (1774) director of the foundery; and, in June, 1779, they were for the first time introduced, and included amongst the established ordnance of the navy.

The first piece of this kind had the following dimensions.

The diameter of its base was eight inches, having the same calibre as an eight inch mortar or howitzer.

The length of its base, including the chamber, was equal to six diameters or calibres, very nearly ; viz. four feet.

The diameter of its chamber was equal to the diameter of a forty-two pounder gun, and contained 5½ pounds of powder.

Its weight was about 31 cwt.

The shot was cast in an eight-inch spherical iron mould, and the windage was only equal to the shrinking of the metal of the shot in cooling ; its weight was about 68 pounds.

Although these carronades were actually employed by the English against the French in 1779, yet they did not come into very general use till the year 1793, viz. at the commencement of the French revolutionary war; but from that time, carronades of various dimensions, but only few of the above heavy construction, were introduced into our ships of war, and these generally for the purpose of throwing hollow or cored shot of the same diameter as the 68 pounder; but continued practice has since so far established their importance, that there are now few ships that are not furnished with a certain proportion of this species of ordnance.

Table of the Dimensions, Weights, Calibres, &c. of the Carronades commonly employed in the British Service.

Calibre in pounds.	Diameter of bore in inches.	Length of bore in inches.		Length of bore in calibre.	Weight.			Ratio of weight of ball to weight of piece.
		ft.	in.		cwt.	qrs.	lbs.	
68	8.05	5	2	7 702	36	0	0	59 : 1
		4	0	5.962	29	0	0	
42	6.84	4	3½	7.518	22	1	0	58 : 1
32	6.35	4	0½	7 670	17	0	14	62 : 1
24	5.68	3	7	7.656	13	0	0	56 : 1
		3	0	6.336	11	1	25	
18	5.16	3	3	7.587	9	0	0	56 : 1
					8	1	25	
12	4.52	2	2	5.778	5	3	10	56 : 1

Diameters of the Principal Parts of Carronades.

Weight of ball.	Greatest diameter.		Least diameter.		Diameter of trunnion.	Diameter of bore.	Diameter of ball.
	ft.	in.	ft.	in	inches.	inches.	inches.
68	1	9	0	11¾	2 000	8.156	8.000
42	1	7	0	11	1 750	6.838	6.684
32	1	5¼	0	10½	1 500	6.257	- -
24	1	3½	0	9¼	1 500	5.690	- -
18	1	2¼	0	8¼	1.250	5 166	- -
12	1	0¼	0	7¼	1.000	4 526	- -

In Plate CCCCXLIV. Figs. 1, and 2. we have shown the exterior and interior lines of construction in a 24 pounder carronade.

Of Howitzers.

The howitzer is a sort of short gun of peculiar form, generally of brass, and intended for throwing shells of different diameters, and from the dimensions of which the piece receives its denomination ; as a ten inch, an eight inch, &c. howitzer : the lighter sort of howitzers are employed in the field, and the heavier ones in sieges, and in the attack of fortified places. Iron howitzers have of late years been constructed, and are preferred for some services, as they will bear a stronger charge, and give a greater range than those of brass, which are so much lighter. The 5½ inch iron howitzer is becoming very common, but those of larger calibre have not yet been constructed in great number. The mean weight of a 5½ inch iron howitzer is 12 cwt.; of the ten inch 40 cwt.; and its length equal to six calibres, or five feet. See the delineation of an iron 5½ inch howitzer, and of an eight inch brass howitzer, in Figs. 3, 4, and 5. of Plate CCCCXLIV.

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* This gun, although still to be seen in our arsenals, has been for some years laid aside in the service.

† Carronades were, we understand, invented by the late Patrick Millar, Esq. of Dalswinton. Ed.

Table showing the Weights and Dimensions of Brass Howitzers in the British Service.

Description.	Length.		Weight.			Length of bore.	Chamber.				
							Length.	Diameter at top.	Diameter at bottom.	Charge.	
	ft.	in.	cwt.	qr.	lb.					lbs.	oz.
10 inch	3	11½	25	3	14	29 inch.	12.6 in.	5.776 in.	4.12 in.	7	0
8 do.	3	1	12	3	12	24 7	8.61	4.6	3.40	3	8
5½ do. heavy			10	0	0					3	0
5½ do. light	2	2¾	4	0	2	18.47	6.02	3.2	2.45	1	0
4⅖ do.	1	1	3	0	13	15.21	4.52	2.7	2.24	0	8

The invention of this species of ordnance is generally attributed to the Germans, who are said to have employed them as early as the year 1690; but their general character was probably very different from those now in use; as we find even in our own service considerable changes in the several dimensions of howitzers, of the same calibre, according to the date of their construction.

The following are the dimensions of the several parts of a brass eight-inch howitzer, according to the most recent practice.

	Inches.
The diameter of the bore	8
The distance of the muzzle to the reinforce	16
The length of the reinforce	10 7
The whole length of the howitzer	37.4
The length of the bore	25.9
The length of the chamber	9.9
The greatest diameter of the chamber	4 6
The least diameter of the chamber	4
The breadth of the muzzle ring	1.25
The distance from the muzzle ring to the astragal	4 6
The breadth of the astragal	0.7
The breadth of the ogee before the reinforce	0.
The breadth of the astragal behind the reinforce	0.7
The breadth of the base ring	1.25
The thickness of the metal at the muzzle	2.25
The thickness of the metal at the muzzle ring	3.4
The thickness of the metal near the reinforce	2.6
The thickness of the metal at the reinforce	3.4
The thickness of the metal behind the reinforce	2.5
The diameter of the base ring	14.7
The diameter at the vent astragal	12.5
The diameter of the cascable	7.6
The diameter of the button	5.
The diameter of the neck	3.5
The breadth of the first ogee and fillets	0.9
The breadth of the second ogee and fillets	0.9
The diameter of the first fillet	9.5
The diameter of the second fillet	4 5
The length and the diameter of each trunnion	4 4
The distance from the fore part of the reinforce to the trunnion	1.2
The chamber contains powder	4 lb. 0 oz.

The weight of the howitzer, from 12 cwt. 3 qr. 0 lb. to 12 cwt. 1 qr. 11 lb.

Of Mortars.

Mortars are a species of ordnance very distinct from those hitherto described; they are short, of great calibre, having the trunnions commonly at the breech, and in general are intended for throwing shells and carcasses. These are generally supposed to have been the first pieces of artillery that were made use of after the invention of gunpowder, and were in the first practice used for throwing balls of red-hot iron, stones, &c. The invention of them is commonly attributed to the Germans, who are said to have actually employed them for military purposes in 1435, when Naples was besieged by Charles VIII.; but whether shells were in this instance thrown out of them is uncertain. It appears, however, to be well authenticated that shells were thrown from mortars at the siege of Wachlendonk, in Guelderland, by the Earl of Mansfield, in 1588, in which year Cyprian Lucas wrote upon the method of filling and charging them, in his Appendix to the Colloquies of Tartaglia, where the methods of composing and throwing carcasses and other fire works are ably discussed.

For many years, mortars have been employed for throwing only shells and carcasses; the former filled with just a sufficiency of powder to explode them, and the time of explosion is so adjusted, that it shall happen just at the moment the shell reaches the ground, which is managed by cutting the fuze to a length proportionate to the intended range. Carcasses, which are also thrown from mortars in bombardments, are a sort of shell with five holes; they are filled with pitch, and other more violent combustible matter, and are intended to set fire to any building on which they may alight. Baskets full of stones about four or five inches in circumference, have been also sometimes projected from this kind of ordnance, into the covert way of a besieged place, in order to annoy and destroy the men employed in its defence. Mortars are in this country, and generally, we believe, on the Continent, distinguished from each other by the diameter of the shell they are intended to throw. Thus, we say, a thirteen-inch, a ten-inch, &c. mortar, and the shells are in like manner called thirteen-inch, ten-inch, &c. although it is the bore of the mortar, and not the diameter of the shell, that has the specified dimensions.

The thirteen-inch mortar is the largest size at present employed in the British service; formerly they extended to eighteen inches, and some of that dimension are occasionally seen in our arsenals; but the use of them has been long discontinued. We have mortars, also, of less calibre, one of which was formerly called a *royal*, having the diameter of its bore equal to 5.62 inches, and the other a *coehorn*, from the name of its first constructor. Its diameter is 4.52 inches.

The principal parts of a mortar on the outside are the chase, including the muzzle, the reinforce, the breech, and the trunnions. The smaller exterior divisions are the vent, the dolphins, the vent astragal and fillets; the breech ring and ogee, the reinforce ring and ogee, the reinforce astragal and fillets, the muzzle astragal and fillets, the muzzle ring and ogee, and the shoulders. The interior parts are the chamber, which receives the charge of powder, the bore, where the shell is lodged, the mouth, and the vent.

The chamber is variously formed by different nations; and even in our own service we have some variety in this respect. The Spanish mortars have spherical chambers, the French, German, and Dutch, are conical and cylindrical. The Portuguese form theirs parabolical, and the English generally in the form of a conic frustum, or cylinder. Nothing appears to have been finally settled as to the best form for this part of the mortar.

These pieces of ordnance are some of brass, and others of iron. Mortars are employed both for land and sea service. Land mortars are those which are used in sieges, and for other land service, mounted on beds, which are transported from place to place on truck carriages. We have had, also, a sort of land mortars mounted on a travelling carriage, which might be elevated to any degree at pleasure.

Sea mortars are those made use of for sea service, such as the bombardment of places by water, &c.; and as the objects they are intended to destroy are generally supposed to be at a greater distance than in land sieges, the latter are made longer and heavier than those employed by land service.

Table of the Weights, Dimensions, &c. of English Land and Sea Mortars.

Nature.			Weight.			Length		Powder contained in the Chamber.		Range at 45°.
Inch.			cwt.	qrs.	lb.	ft.	in.	lbs.	oz.	yards.
13	Brass	Sea Serv.	82	0	8	5	3	32	0	4100
	Iron		82*	1	0			20	0	
	Brass	Land do.	25	0	10	3	7½	9	12	2100
	Iron		36	2	12			9	8	
10	Brass	Sea Serv.	33	0	0	4	8	12	8	3800
	Iron		41	0	0			10	0	
	Brass	Land do.	10	1	25	2	9	4	10	1900
	Iron		16	0	6			4	8	
8	Brass	Do. do.	4	1	8	2	1¾	2	0	1600
	Iron		8	0	11			2	4	
5½	Brass	do. do.	1	0	20	1	4¾	0	9	1200
4⅖	Brass	do. do.	0	3	11	1	1½	0	4½	1000

The principal dimensions of the several parts of land and sea mortars, according to the most general practice, are shown in the following Tables:

Table of the Dimensions of Brass Land Mortars commonly employed in the British Service.

Particular Parts.	Description of Mortar.				
	13 Inch.	10 Inch.	8 Inch.	5.6 Inch.	4.5 Inch.
Diameter of the bore	13	10	8	56	4.5
Total length of the mortar	44	33	25.5 to 26	16 to 16.5	13.5
Distance from the muzzle to the reinforce	15.25	10	8 5	4.75	4.2
The length of the reinforce	8.75	8.1	5	5	3.9
The length of the trunnions, from end to end	32.5	26	20	12	9.2
Diameter of the trunnions	7.15	6.3	5	2.75	2.15
The length of the bore	24	18	13	8.5	7
Length of the chamber	12	7.8	7.75	4 3	3 7
Greatest diameter of the chamber	6.6	4.5	4	3	2.7
Least diameter of the chamber	6	3.6	3 4	2.4	1.4
The diameter of the muzzle ring	21	15 15	11 2	8	6 4
The breadth of the muzzle ring	11	0 8	0.7	0.6	0.5
The breadth of the astragals and fillets	1.25	1	0.75	0	0
Their distance from the muzzle ring	1.5	1	1	0	0
The diameter near the muzzle astragal	18.1	13.2	10	6.9	5 6
The diameter near the reinforce	18.1	13.2	10	6 9	5.6
The diameter of the reinforce	21	15.15	15.1	8	6 4
The breadth of the ogees	1.5	1	1	0	0
The diameter behind the breech astragal	18.1	13.2	9.8	6.9	5.9
	lb. oz. gr.	lb. oz. gr.	lb. oz. gr.	lb. oz. gr.	lb. oz. gr.
Chambers contain powder	9 1 8	4 0 0	2 0 10	1 0 10	0 8 0

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* There are a few iron mortars of recent construction, in the arsenal at Woolwich, weighing 101 cwt.

In Plate CCCCXLIV. Fig. 6. we have given a section, plan, and elevation, of this description of mortars, the diameter being 10 inches.

Table showing the Dimensions of the several Parts of Sea Mortars employed in the British Service.

Parts of the Mortar.	Description of Mortar. 13 Inch.	10 Inch.
	Inches.	Inches.
The diameter of the bore	13	10
The whole length of the mortar	63	56
The distance from the muzzle to the reinforce	21	20
The length of the reinforce	18	12
The length of the bore	24	30
The length of the chamber	21	15
The greatest diam. of the chamber	8.5	6.6
The least diameter of the chamber	7	6
The breadth of the muzzle ring	3	2.4
The breadth of the muzzle ogee and fillet	1.9	0
From the muzzle to the astragal	0	0.4
The breadth of the astragal	0	1.6
The breadth of the reinforce ring	1.9	0
The breadth of the ogee next to the reinforce ring	4.5	2.2
The breadth of the chace ring	1.5	0
The breadth of the chace ogee	2.2	0
The breadth of the chamb. astragal	0	1.6
The thickness of the metal at the muzzle	4.7	2.8
The thickness of the metal at the muzzle-ring	5¾	6
The thickness of the metal near the reinforce	4.7	3.3
The thickness of the metal at the reinforce	8	6
The thickness of the metal behind the reinforce	9.5	6
The length of the trunnion from end to end	45.4	3.6
Its greatest diameter	12	8
Its least diameter	10	8
Length of the part diminished at each end	6	0
	lb. oz. gr.	lb. oz. gr.
The chamber contains powder	32 0 0	12 8 0

The thickness of the metal at the muzzle, and near the reinforce, is taken or measured from the lines produced, which determine the bore of the mortar; and behind the reinforce it is reckoned from the lines which terminate the chamber. The round part of the breech of the mortar is circular; and, in the ten-inch mortar, is described from the same centre that the bottom of its chamber is described from. But in the thirteen-inch mortar it is described from a centre about three and a half inches nearer to the end of the mortar than that from which the bottom of the chamber is described, and in both, these arcs ought to touch right lines drawn parallel to the sides of the chamber.

Stone Mortars.—These are light mortars, generally of brass, and about fifteen inches interior diameter; they are intended to throw stones to small distances; viz. into the covert way, &c.; and hence their denomination. They are not employed in the British service.

Hand-mortars were also formerly used for annoyance at inconsiderable distances, by a single gunner or bombardier. These, however, have been long laid aside.

Of Petards.

Petards are small and peculiarly formed pieces of iron, or gun metal, resembling in figure the frustum of a cone. At the centre of the less end is a fuze hole, something like that of a shell. When loaded, it is fastened by bands of iron, screwed to a square board two inches thick, carrying a hook of iron. The purpose of this machine is to force open the gates of a fortress, or of a barrier; to throw down a wall or a row of palisades, &c.; it is attached to whatever it is intended to destroy, and is supported in its position by props and forks.

There are four different dimensions of petards; the first or largest contains 12 lbs. 13 oz. of powder; the second, 10 lbs. 11 oz.; the third, 1 lb. 10 oz. and the fourth, 1 lb. The stores for one petard are as below.

Hooks to hang the petard	2	Gimblets - -	2
Brass fuze - -	1	Wrench for fuze	1
Blue paper portfires	6	Slow match -	6 yds.
Props, or forks -	2	Copper funnel -	1
Tallow - - -	8 ozs.	Cartridge - -	1

Of Shot, Shells, Carcasses, &c.

Shot, which is meant to signify solid balls only, is distinguished by the following designations.

Round Shot, which are the single balls fired from different descriptions of cannon, &c.

The usual weights and corresponding diameter of the round shot in the English service, are as below.

Weight.	Diameter.	Weight.	Diameter.
68	8 inches.	12	4.403 inches.
42	6.684	9	4.000
32	6.105	6	3.498
24	5.475	3	2.775
18	5.043	1	1.920

Case or *Cannister Shot*, are small shot inclosed in tin cases, which latter are burst by the explosion of the powder, and the balls spread about in all directions.

Tier Shot are something of a like kind; they are inclosed in a case, but arranged in tiers, and the balls are sometimes larger.

Table showing the Number and Weight of Case Shot for different Pieces and for different Services.

Cannon.	SEA SERVICE. Weight of each shot.	Number in each case.	Weight of each case filled.
32 Pounders.	8 oz.	70	33 lb. 8 oz.
24 do.	8	42	22 15
18 do.	6	42	16 8
12 do.	4	42	11 5
9 do.	3	44	8 9
6 do.	2	40	5 2
4 do.	2	28	4 0
3 do.	2	20	2 15
1 do.	1½	12	1 2½

Table—Continued.

Cannon.	Land Service.		
	Weight of each Shot.	Number in each case.	Weight of each case filled.
24 Pounders.	4 oz.	84	21lb. 11 oz.
12 do.	2	84	12 1
6 do.	1½	55	5 10½
3 do.	1¼	52	2 14
Carronades.	Sea Service.		
68 pounders.	8 oz.	90	46lb. 2 oz.
42 do.	8	66	32 8
32 do.	8	40	21 4
24 do.	8	32	16 1
18 do.	6	31	12 2
12 do.	4	32	8 2
Mortars.	Land Service.		
10 inch.		170	91lb. 8 oz.
8 do.	6	90	38 4
5½ do.	3	55	12 6
4⅖ do.	2	55	8 1¾
Howitzers.	Land Service.		
8 inch.	6	90	38lb. 8 oz.
5½ do.	3	55	12 8
4⅖ do.	2	55	8 2
Cannon with tier shot.	Field Service.		
12 pounders.	18 oz.	15	18lb. 8 oz.
Medium.	6½	42	17 11
6 pounders.	8½	15	9 0
Medium.	3½	42	8 14
3 pounders.	4½	15	4 10
Medium.	1½	42	4 6
12 pounders.	14	12	14 14
Light.	6½	34	14 11
6 pounders.	8½	12	7 3
Light.	3½	34	7 7
3 pounders.	4½	12	3 10
Light.	1½	34	3 11

Grape shot is a combination of small shot put into a thick canvass bag, and corded strongly together, so as to form a kind of cylinder, whose diameter is equal to that of the ball adapted to the cannon.

Table of Grape Shot for Sea and Land Service.

Description.	Weight of each Shot.	Total weight of the Grape complete.
42 pounders.	4lb. 0 oz.	46 lb. 6 oz.
32 do.	3 0	34 1
24 do.	2 0	25 5
18 do.	1 8	19 15½
12 do.	1 0	10 15
9 do.	0 13	7 6
6 do.	0 8	5 8½
4 2o.	0 6	3 14½
3 do.	0 4	2 10½
½ do.	0 0¾ lead.	8¾

Besides the above description of shot we have had formerly, and even at present perhaps, occasionally, other descriptions, as chain, bar, and langrel shot. The chain-shot consist of two balls connected by a chain, and the bar-shot of two balls connected by a bar, &c.

Shells.—These, as the term implies, are hollow iron balls, which are intended to be filled with a sufficient quantity of powder to explode them at the extremity of their ranges, and are of different diameters corresponding with those of the mortars or howitzers from which they are intended to be thrown. They have a fuze hole, into which the fuze is inserted, and the length of the latter is so proportioned to the range and time of flight, as to fire the powder at the moment the shells reach the ground. A second description of shells, having an equal thickness of metal throughout, being made with somewhat more precaution than the preceding, are intended for guns and carronades, and have, therefore, a corresponding diameter.

Table of the several particulars relating to Mortar and Howitzer shells.

Description.	Weight.				Diameter.	Powder the Shell would contain.		Powder for bursting.		Diameter of Fuze Hole.		Thickness of Metal.
	cwt.	qrs.	lbs.	oz.						Outside.	Inside.	
13	1	3	2	0	12¾	10	4	6	12	1.837	1.696	2.05
10	0	3	9	0	9¾	4	5	2	10	1.57	1.45	2.575
8	0	1	11½	0	7¼	2	12	1	14	1 219	1.127	1.2
5½	0	0	15¼	0	5¼	1	0	0	12	0.894	.826	0.822
4⅖	0	0	8	0	4⅕	0	7	0	5	0.832	.769	0.653
Hand	0	0	3	11	3.49							
Grenades.	0	0	1	13	2.27			0	1½			

Table of the Dimensions of Shells for Guns and Carronades.

Description.			42 pr.	32 pr.	24 pr.	18 pr.	12 pr.
			Inches.	Inches.	Inches.	Inches.	Inches.
Guns.	Diameter of the shell.	Exterior	6.684	6.105	5.547	5.05	4.4
		Interior	4.404	4.005	3.767	3.4	2.8
	Thickness of metal		1.140	1.05	0.89	0.82	0.8
	Diameter of the fuse hole	Exterior	0.894	0.894	0.893	0.832	0 832
		Interior	0.826	0.826	.826	.76	0.769
	Thickness of metal		.14	.11	.12	.9	.5½
Carronades.	Diameter of the shell	Exterior	6.64	6 05	5.48	4.935	4.295
		Interior	4.36	3.95	3.48	3.235	2.695
	Thickness of metal		1.14	1.35	1.	.85	0.98
	Weight of shell			22 lbs.		12lbs.	
	Contains powder			12½ oz.		9 oz.	
	Powder for bursting			10 oz.		7 oz.	

Shrapnell Shells are a particular description of shells, thus called, from the name of their inventor, General Shrapnell. They are intended for field service, are much thinner, and are more accurately formed, than the common shell. They are filled with small balls, and a quantity of bursting powder, and are intended to explode at the moment they reach an enemy's line. At this time the balls, having the velocity of the shell, are, when the latter explodes, spread in all directions, and produce the most destructive effect upon the line. These were formerly denominated *spherical case shot;* but they are now always spoken of under the term Shrapnell shells.

Carcasses. These are also a sort of shell, having four, five, or more holes. They are filled with a strong combustible matter, and are intended to destroy any building, or other place on which they fall. Their principal application is in bombardments.

Table of the Weight and Dimensions of Carcasses.

Description.		Weight.									
		Empty.			Of Composition.			Complete.			Time each will burn
		lb.	oz.	dr.	lb.	oz.	dr.	lb.	oz.	dr.	Minutes.
Round for Mortars and Howitzers	13	194	10	11	18	14	0	213	8	16	11
	10	88	13	11	7	8	11	97	6	11	8½
	8	44	9	5	4	4	11	48	14	0	5½
For Guns	42	27	3	0	2	7	11	29	10	11	5
	32	20	13	5	1	14	5	22	11	11	4½
	24	14	12	0	1	9	11	16	5	11	4
	18	11	13	11	1	1	5	12	15	0	4
For Carronades	68	...	...	...	...	...	...	...	...	...	...
	42	26	0	0	2	7	0	28	7	0	4½
	32	21	10	0	1	13	0	23	7	0	4
	24	14	5	0	2	5	0	16	10	0	3½
	18	10	4	0	1	2	0	11	6	0	3
Oblong for Mortars and Howitzers	10	36	7	5	35	10	0	72	1	5	12
	8	16	5	5	18	2	0	34	7	5	10
	5½	1	12	2	6	15	0	8	11	3	6
	4⅖	1	0	6	8	11	7	4	11	13	4

Rules for Computing the Number of Shot or Shells in a Pile.

Shot, shells, &c. are, in store, arranged in piles, having square, rectangular, or triangular bases, and decreasing upwards till they terminate either in a single ball in the square and triangular pile, or in a line in the rectangular one.

And the number of balls in any proposed pile is found by the following general formulæ:

$$\text{Square pile, No. of balls} = \frac{n\,(n+1)\,(2\,n+1)}{1\,.\,2\,.\,3}$$

$$\text{Triangular pile, No. of balls} = \frac{n\,(n+1)\,(n+2)}{1\,.\,2\,.\,3}$$

$$\text{Rectangular pile, No. of balls} = \frac{b\,(b+1)\,(3\,l-b+1)}{1\,.\,2\,.\,3}$$

Where n is the number of balls in the bottom row in the two first piles, and b the number in the breadth, and l those in the length of the latter pile.

Of Ordnance Carriages.

The construction of carriages for the different species of ordnance is a subject by no means of less importance than the construction of the pieces themselves. It is not only necessary that a piece of ordnance should be the most effectual with the least quantity of material, as far as regards its own projectile power; it is also requisite that it should be so supported, adjusted, and arranged, as to have its fire repeated the greatest possible number of times in a given interval; and such at the same time, that it may be directed, removed, and transferred from place to place with the greatest facility. And when we consider the enormous mass of some of the larger ordnance, and the very considerable weight even of the medium pieces, we may soon be convinced that much scope is given to the ingenuity of the practical artillerist, to construct carriages that shall possess advantages peculiar to the service for which any proposed piece of ordnance is intended, and that the subject upon which we are now about to enter is of considerable extent, and, taken in a military point of view, of the greatest importance. Our limits, however, will not admit, nor does the nature of our work require, that we should enter upon the subject at length, and with the most minute detail; all that we can attempt in this place is, to give a general view of the different description of ordnance carriages, and to supply, as far as possible, by figures, what we are obliged to pass over, somewhat slightly, in the text.

Different Descriptions of Carriages.

These may be classed under the following general denominations, viz.

Travelling carriages, for heavy field ordnance, which are such as guns are mounted upon, and by means of which they are transported from place to place when employed in sieges, or in the field. See Plate CCCCXLV.

Travelling carriages, for the lighter field pieces, which may be advanced by men only, and managed with the greatest dexterity. The gun carriage itself consists of two wheels and the trail, which, when advanced by horses, or in the line of march, is connected with what is termed the limber, which has also two wheels, and is connected with the gun carriage by means of a strong iron pin.

Howitzer carriages are for supporting and transporting howitzers. Those for the smaller kind are made with screws for elevating them, in the same manner as the light six pounder carriages are. They are, therefore, made without a bed; and the centre transome is nine inches broad, for the purpose of receiving the elevating screw, instead of four inches, as in those which are made without such a screw. In the centre, between the trail and centre transome, there is a transome bolt, which is not in others, because the centre transome must be made to be taken out; and when it is, the howitzer may be elevated at pleasure. In Plate CCCCXLV. we have shown the howitzer carriage complete, its limbers, &c. &c.

Garrison carriages are those on which the garrison guns are commonly mounted. These are of various kinds, much depending upon their particular locality. The more common ones are supported and moved on four cast iron trucks, or small low wheels, seldom exceeding two feet in diameter.

Traversing platform and carriage, is a construction intended to facilitate the direction of a gun to any required object within certain limits, according to its situation. Some are made to traverse 60°, others 90°, and some may be passed through the entire circle. The carriage itself, however, in these constructions, is the same as usual, and the platform itself is the only peculiarity.

Ship gun carriages, of the common structure, differ from the garrison gun carriages only in their having wooden trucks and breech rings, which the others have not; but, of late years, great improvements have been made in ship, gun, and carronade carriages, by Sir William Congreve, of which some particulars are shown in Plate CCCCXLV. We have also a variety of other denominations of carriages in the ordnance land service, as galloper carriages, devil carriages, tumbrel carriages, block carriages, truck carriages, pontoon carriages, &c. &c. which the limits of this article will not admit of our noticing more particularly.

Of the Weights, Dimensions, &c. of the Principal Carriages for Land Ordnance.

The uniformity observed in the British service in the several branches of the military art, has been carried to that degree of perfection, that in the particular case in question, viz. the construction of the carriages, not only the whole of every complete carriage for any specified pieces, has the same weight and dimensions, but the several parts of the same, from the largest to the most minute, only differ from each other in the former respect, so far as the materials of which they are composed may differ in the specific gravity; in the latter respect, that is to say, in dimension, no difference is allowed.

Weight of travelling carriages, with limbers complete, exclusive of the gun.

	cwt.	qr.	lb.
24 pounders, iron, 9 feet 6 inches, carriage, weight	28	2	27
18 pounder, iron, 9 feet, ditto	25	1	27
12 pounder, iron, 9 feet, ditto	24	0	6
12 pounder, iron, 6 feet, ditto	18	1	4
24 pounder, or 5½ inch howitzer, ditto	17	3	5

Weight of the new block trail carriages, and new patent ammunition carriage, when equipped.

	cwt.	qr.	lb.
12 pounders medium, gun carriage and limber, with ammunition	42	0	0
Ammunition carriage, and limber to ditto, with ammunition	29	0	0
9 pounder gun, &c.	39	1	0
Ammunition carriage, &c. for ditto	26	0	0
6 pounder heavy gun, &c.	37	2	0
Ammunition carriage, &c. for ditto	27	2	0
6 pounder light gun, &c.	27	2	0
Ammunition carriage, &c. for ditto	26	0	0
3 pounder heavy gun, &c.	26	0	0
Ammunition carriage, &c. for ditto	23	2	0
8 inch howitzer, &c.	40	3	2
5½ ditto, heavy	36	1	0
Ammunition carriage, &c. for ditto	27	1	5
5½ inch howitzers, light,	27	1	0
Ammunition carriage, &c. for ditto	27	0	0
Ditto 6 pounder, wheel carriage complete	27	0	24

Weight of park carriages.

	cwt.	qr.	lb.
Ball cartridge cart, empty	8	0	20
Ditto, loaded	21	1	14
Hand cart	3	3	0
French cart	4	3	27
Truck carriage	12	2	21
Sling cart	15	0	2
Large devil carriage and limber	27	3	0
Small ditto	7	2	3
Cavalry forge cart, with stores	11	3	18
Forge waggon, with limber and stores	21	2	23
Store waggon, with limber, empty	17	3	21

All the field carriages are now made with iron axletrees, which are more durable than wood; their diameters being less, the friction is thereby decreased, and they require less grease. There are but two sorts used, heavy and light.

Weight of brass howitzer standing carriages.

	cwt.	qr.	lb.
10 inch	21	1	7
8 inch	16	2	23

Standing gun carriages of cast iron have lately been introduced into the service for warm climates, and situations not much exposed. Their weight, including the trucks, are as follows:

		cwt.	qr.	lb.
32 pounder	-	25	2	0
24 ditto	-	19	3	25
18 ditto	-	16	3	0
12 ditto	-	16	1	0
9 ditto	-	15	0	0
6 ditto	-	14	3	0

An experiment was made at Sutton Heath, 1810, with an 18 pounder, iron carriage, which stood the first part of the practice, with high charges and elevations; but afterwards the bed broke with a reduced charge and low elevation. The trunnion of an 18 pounder gun, on a cast-iron carriage, at Landguard Fort, broke off the same year, at the twenty-seventh round on the day of practice.

Dimensions and Weights of standing Gun Carriages.

DESCRIPTION.	Forty-two Pounders.	Thirty-two Pounders.	Twenty-four Pounders.	Eighteen Pounders.	Twelve Pounders.	Nine Pounders.	Six Pounders.
	ft. in.	*ft. in.*	*ft. in.*	*ft. in.*	*ft. in.*	*ft. in.*	*ft. in.*
Axle-tree, total length	5 0	4 10	4 6½	4 5	4 1	4 0	3 10
Axle-tree, depth, fore	0 11	0 11	0 11	0 10½	0 10½	0 10½	0 9½
Axle-tree, depth, hind	0 7¾	0 7¾	0 6¾	0 6¾	0 6¾	0 6¾	0 5¾
Axle-tree, thickness, fore & hind	0 7¾	0 7¼	0 6¾	0 6¾	0 6¾	0 6¾	0 5¾
Axle-tree, width	1 0	1 0	1 0	1 0	1 0	1 0	1 0
Length of bracket	6 5	6 3	6 2	6 1	5 9	5 8¼	5 7
Thickness of ditto	0 6	0 6	0 5½	0 5	0 4½	0 4	0 3½
Depth of ditto	2 3	2 2½	2 2	2 1	2 1	2 0	2 0
Width, before	1 6¾	1 5½	1 4¾	1 3¾	1 1⅞	1 0⅞	0 11¾
Width, behind	2 0½	1 11¾	1 11	1 9	1 7½	1 6½	1 5¼
Diameter of iron trucks, fore	1 6¾	1 6¼	1 6¾	1 6¾	1 6¾	1 6¾	1 6¾
Diameter of iron trucks, hind	1 3¼	1 3¾	1 3¼	1 3¾	1 3¾	1 3¾	1 3¾
Diameter of arm of axle one-fourth of an inch less than the bore of the truck	0 7½	0 7½	0 7½	0 6½	0 6½	0 6½	0 5½
	cwt. qr. lb.	*cwt. qr. lb.*	*cwt. qr. lb.*	*cwt. qr. lb.*	*cwt. qr. lb.*	*cwt. qr. lb*	*cwt. qr. lb.*
Weights of the carriages, bed, trucks, and coins, complete	16 3 13	15 1 0	13 2 0	12 3 0	11 3 0	10 1 0	9 1 0

Of Mortar Beds.

A mortar bed is intended to mount a mortar upon, as we do a gun on its carriage. Land mortar beds are commonly made solid, each of them consisting of four pieces of timber, well secured, and strongly fastened together with iron work, except those for the smaller sort, which are generally formed out of single blocks. Iron mortar beds are also now common in the English service. Sea mortar beds are also made solid with very strong timber, but they differ from the land mortar beds in their form. They have each a hole in the middle or centre for receiving the iron bolt on which the bed turns. They are placed on strong wooden frames fixed into the bomb ketches, to which the bolt is fastened. The fore part of a sea mortar bed is an arc of a circle described from the centre of the hole above mentioned.

Table of the weight, tonnage, and dimensions of Mortar Beds, for land and sea service

Description of Mortar.	Weight.	Tonnage.	Length.	Breadth.	Height.
	cwt. qr. lb.	*ton. cwt. qr*	*ft. in.*	*ft. in.*	*ft. in.*
13 Inch sea mortar	38 3 13	3 3 2			
13 Land mortar, wood	21 2 7	1 6 0	7 0	2 6	2 3
13 Ditto, iron	50 0 0	2 10 0	6 3	3 1	1 6
10 Sea mortar	32 2 14	2 2 2			
10 Land mortar, wood	10 0 20	0 14 2	6 6	1 8	1 10
10 Ditto, iron	23 0 0	1 3 0	4 8	2 4	1 1½
8 Land mortar, wood	6 0 20	0 7 2	4 2	1 7	1 7½
8 Ditto, iron	12 0 0	0 12 10	4 0	1 11	0 11
5½ Land mortar, wood	1 0 22	0 2 0	2 9	1 4	0 10
4⅖ Ditto, wood	0 3 11	0 1 2	2 4½	1 2	0 9

Rockets.

The construction, principle, and practice of military rockets, which may now be considered as a permanent branch of the British ordnance, will be treated of under the article **PYROTECHNY**.

For further information on this subject, see our articles **ARTILLERY**, and **GUNNERY**.

ORGAN.

Organ, an instrument of music. The word is Greek, οϱγανον, which signifies instrument of any kind, and is very appropriately given, by way of eminence, to this incomparably the grandest among musical inntruments.

In the short abstract of the history of the art, given under the word Music, we have noticed (Art. 27.) the important effects which the invention of this instrument, and its introduction into the church service, gradually produced on the science or art; and that it was probably an improvement on the Hydraulic Organ of the ancients.

Of this ancient instrument, so little is known, notwithstanding the long description of it given by Vitruvius, and the labours of learned men to explain that description, that we shall be content with quoting what Dr. Burney says of it in the short account he has given of ancient instruments of music, at the end of the first volume of his History.

"The last wind instrument of which I shall speak, is the Hydraulicon or water-organ, that was played, or at least blown, by a cataract or fall of water. Indeed, it has been much disputed, whether it was played by fingers, by means of levers, or keys; and yet the description of it by Claudian seems such as would suit a modern organ, only blown by water instead of bellows.

Vel qui, magna levi detrudens murmura tactu,
Innumeras voces, segetis moderator aenae,
Intonet erranti digito, penitusque trabali
Vecte laborantes in carmina concitet undas.

"In Athenæus, lib. iv. p. 174, there is a history and description of this instrument. He tells us that it was invented in the time of the second Ptolemy Euergetes, by Ctesibius, a native of Alexandria, and by profession a barber; or rather, it was improved by him; for Plato furnished the first idea of the hydraulic organ, by inventing a night clock, which, according to Perrault, Vitruv. lib. 10. was a clepsydra, or water clock, which played upon flutes the hours of the night, at a time when they could not be seen on the index.

"This musical clock must have been wholly played on by mechanism. But neither the description of the hydraulic organ in Vitruvius, nor the conjectures of his innumerable commentators, have put it in the power of the moderns either to imitate, or perfectly to conceive the manner of its construction; and it still remains a doubt, whether it was ever worthy of the praises which the poets have bestowed upon it, or superior to the wretched remains of the invention still to be seen in the grottos of the vineyards near the city of Rome.

"In the collection of antiquities bequeathed by Christina, Queen of Sweden, to the Vatican, there is a large and beautiful medallion of Valentinian, on the reverse of which is represented an hydraulic organ, with two men, one on the right, and one on the left, who seem to pump the water which plays it, and to listen to its sounds. It has only eight pipes, placed on a round pedestal; and as no keys or performers appear, it is probable that it was played on by mechanism."

The pneumatic organ, as the modern instrument blown by bellows has been called, in contradistinction to the hydraulic one, is a very complicated and ingenious piece of mechanism. Although it is spoken of as one instrument, yet, strictly speaking, it is a collection of many instruments, all brought under the finger of one performer, and so ingeniously contrived, that he has it in his power to play on any one singly, or to combine several, or all, according to his taste, in order to produce variety of effect. If we suppose an instrument having a set of pipes, giving the twelve notes of the chromatic scale, corresponding to each octave in the key-board of keyed instruments, described under Music, Art. 80–87, we have the idea of the simplest organ; and such an instrument, provided its key-board were as extensive, would be as complete, as far as regards the scale, as the piano-forte. But organs have many sets of pipes, or stops, as they are called, of very different qualities, to the same key-board, and frequently several key-boards, each having many stops belonging to it; insomuch, that the grandeur and variety of effect which it puts in the power of an able organist to produce, is almost endless. Of the mechanism by which this is effected, we are now to give as minute an account as our limits permit; and we shall begin by describing the pipes, the grand assemblage of which constitutes the organ.

Organ pipes are of two general descriptions, mouth-pipes, and reed-pipes: each of these are of several different species.

Mouth-pipes are either of wood or metal, which differ something in shape, but which are formed on the same principle.

A wooden mouth-pipe consists of a right angled tube, Plate CCCCXLVI. Fig. 14. AA, BB, formed by four plane boads glued together, and usually sized with glue on the inside. The cross section of the pipe is not square, but oblong, one side being to the other as 5 to 4. The pipe is at one end, either quite open, or closely stopped, as at AA, by a plug or *tompion* C, Fig. 15. covered with leather, so as to be quite air-tight. The other end of the pipe is closed by the *block* D, on which three of the walls are glued, except at the narrow aperture across the front wall, called the mouth *a*. The mouth is formed by the front wall being cut off a little above the upper part of the block, and at the same time bevelled from the front surface at *b*, so as to form a sharp edge with the back or inner surface of the wall at *a*, called the *upper lip* or *wind cutter*. The side walls and back wall of the pipe extend beyond the *block* D, and again embrace another block, leaving a narrow space between the two *c*. This lowest block is pierced to receive the *foot* E, which is a hollow cylinder open at both ends, glued into the lowest block, and formed at the other end to be received into a hole in the *upper board*, to be afterwards described. The cap F, Fig. 17. is a piece of mahogany, or other hard wood, somewhat thicker than the walls of the pipe, which covers that part of the front of the pipe from the mouth downwards. It is hollowed out, leaving edges to be glued upon those of the side walls, and upon the block into which the foot is inserted, but leaving the aperture *c* quite free. The upper edge of the hollow *c* is a straight line, but retired a little from the level of the edges, so that when the cap is applied, there is a thin aperture between it and the block D, called the *plate of wind*. From the line *e*, the inner part of the cap is formed into a curved surface, so that it grows considerably deeper as it descends, leaving the greatest interval opposite the opening *c*. When therefore the cap is glued on, Fig. 13. and the pipe is set in its place, the wind is blown into the aperture *d*, passes between the block and the cap, and is forced in a thin stream against the upper lip or wind cutter *a*; and being thus thrown into a vibratory motion, communicates this motion to the column of air within the pipe, and makes it sound; just as the drawing the bow across the strings of a violin causes them to vibrate, and consequently, to speak their respective notes.

To produce this effect, however, at least in the best manner, so as to give a good quality of sound, the pipe must be properly *voiced*. We have described the curved-wedge-shaped hollow in the cap, and the thin aperture called the plate of wind. Now, in voicing the pipe, before the cap be put on, the upper corner, or edge of the block, is slightly pared away, opposite the upper lip *a*, so as to direct the wind against the edge of it, or rather more inwardly. Experience teaches the degree in which the corner is to be pared off. If it be done too much, or too little, the pipe will not speak, or will speak ill, or will be slow to speak. At the same time the upper part of the block is, by the edge of an angular file, toothed by thin cuts or lines running parallel to each other, but not at right angles to the under lip; deepest and widest at the mouth, and wearing gradually out as they recede from it, till they are lost in the plane surface of the block. This voicing is shown in Fig. 14. The use of it is to carry smoothly, and at the same time to divide the wind in its passage into the pipe. If the plate of wind were suffered to strike against the upper lip in an entire body, the tone would be imperfect, and accompanied with a disagreeable chirping at the commencement of the pipes speaking. The nice voicing, therefore, is of capital importance, and on the manner of doing it depends the quality of the organ.

The width of the mouth, also, or the distance of the upper lip from the plate of wind, is of much importance. If this distance be too great, the pipe will be slow to speak, or will not speak at all. If the mouth be too narrow, an open pipe will speak the octave, or even the double octave of the note which it is intended to give, and a stopped one the twelfth.

The proportion between the size of the tube and length of the pipe, though it has no effect on the acuteness or gravity, has a decided effect on the quality of the tone; and as it is essential to have all the notes of any one stop as nearly alike as possible in quality, organ-builders have regular scales by which each pipe in any one stop is formed, from the largest up to the smallest. Stops are of very different scales for large church organs, and for chamber organs; and stops of different scales are admitted for variety into the same organ.

All the pipes in one stop are to be regulated as equally as possible in respect of loudness and softness. This is chiefly effected by enlarging or diminishing the aperture of the foot *d*, which consequently regulates the quantity of wind admitted into the pipe.

The *note* which the pipe speaks depends on the length of the tube; a stopped pipe, therefore, as Fig. 14. is tuned by means of the *tompion*, or plug. If this be pushed deeper into the tube, so as to shorten the column of air within the pipe, the note will be more acute; and *vice versa*. If the tompion were taken out altogether the pipe would give exactly the octave above what it would give if stopped at the very top AA. A stop of open pipes, therefore, in order to speak in unison with a stop of shut pipes, must be double the length of the latter. An open pipe is tuned by means of a thin plate of lead, Fig. 16. *a*, fastened at the upper end, and bent over the open tube more or less to depress or raise the pitch. Open pipes are also usually of larger diameter than shut or stopped pipes in unison with them. Thus, in the unison stops, called the open and stopped diapasons, the unison in the stopped diapason to C of the open diapason, would be of the same diameter as the G above of the latter stop.

The quality of the tone of wooden pipes is influenced also by the material or wood used. Thus mahogany, or wainscot pipes, have a clearer tone than pipes of fir or other soft wood: on the other hand, the latter are more mellow.

Metal mouth pipes are made on the same principle. Such a pipe consists of a cylindrical tube, Plate CCCCXLVI. Fig. 9. A. The mouth is formed by a portion of the cylinder flattened, and retiring inwards *b a*; the upper lip *a* being cut a little shorter than the remaining part of the circumference. The foot B is a cone, open at the apex *c*, but closed at its base by a piece of pretty thick metal *d*, Fig. 9. called the *languette*, (which corresponds to the *block* of a wooden pipe,) except a thin opening or plate of wind. Part of the conical surface of the foot, towards the mouth of the pipe, is flattened, and retires inwardly to meet the upper lip *e a*, and consequently the languette is here cut to a straight edge. The edge of the languette, which, with the under lip, forms the *plate of wind*, is bevelled inwards and upwards to direct the wind duly on the upper lip; and the *voicing* is performed by making notches on this bevelled surface parallel to each other, and at an angle to the axis of the pipe.

Metal pipes are either open or stopped, and what is said of wooden pipes is equally applicable to them. There is a third kind, called chimney-top pipes, Fig. 10. which have a small open tube *a* inserted in the middle of the top plate; the effect of which is to make the note considerably sharper than if it were quite stopped. This is also sometimes imitated by boring a small hole through the tompion of stopped wooden pipes.

Stopped metal and chimney-topped pipes have large *ears f f*, Fig. 10. one on each side the mouth, by means of which they are tuned. Bending the ears towards the mouth flattens the note; and *vice versa*. The larger open metal pipes, that is, more than a foot in length, have also small ears *f f*, Fig. 9. which make them speak better. Open pipes are tuned by lessening or enlarging the diameter of the open end.

The metal used is a mixture of tin and lead, in different proportions, to which a little bismuth is sometimes added, or occasionally a very little copper. The metal is cast in thin plates, and then planed to the requisite thickness.

Reed pipes are made to speak by an apparatus very different from what we have described. Fig. 7. Plate CCCCXLVI. *a a*, *b b*, is a brass cylindrical, or rather slightly conical, tube, *b b* being the widest end, having a longitudinal narrow opening in the front. The end *b b* is cut slanting upwards and backwards, and is closed by a piece soldered on it. The tongue *a c* is a thin plate of metal, which lies upon the longitudinal opening of the reed, firmly kept to the reed at its upper end *a*, but free at the lower end, and slightly curved away from the reed. This apparatus is firmly fixed in a solid block *d*, Fig. 5. the open end of the reed passing through it. The tuning spring *e e e*, Fig. 5. and 7. is a piece of wire which passes through the block, and, bending up towards the top of the tongue, presses firmly against it, keeping it close to the reed, and, by being pushed down or drawn up, shortens or lengthens the free part of the tongue, for the purpose of tuning. The foot, or socket A, Fig. 6. is a cone in which the lower part of the block, with the reed, tongue, and tuning spring, are inclosed, and is quite closed by the block at its large end, but open at the apex *f* to receive the wind. The tube, properly so called, is of various shapes, B, Fig. 4, 5, 6, 11, 12. This tube gives the quality of the tone, and makes the difference between the different kinds of reed-pipes. Fig. 5. and 6. is the *trumpet*; Fig. 11. the *oboe*; Fig. 12. the *cromorna*, vulgarly called the *cremona*; Fig. 4. the *vox humana*; which last produces a quality of tone resembling the human voice, but generally of very poor effect. The tube of the *bassoon* is a long narrow cone, Fig. 19. the quality of which is much thinner and less powerful than the trumpet.

When the pipe is set in its place, the wind fills the socket, and presses the tongue against the reed, shutting the longitudinal opening: the elasticity of the tongue immediately carries it farther off than its position at rest; it is again forced against the opening, and again recedes; and thus, by its vibrations, gives the note which the pipe is to speak. As the tongue, by means of the tuning-spring, is lengthened or shortened, its vibrations are slower or quicker, and the note, of consequence, lower or higher.

The goodness of a reed-pipe depends on several circumstances: 1st, The composition of the metal of which the tongue is made. Some organ-builders use common brass, others a composition with a larger proportion of copper. 2d, The thickness of the plate of which the tongue is made, which varies according to the weight on the bellows, or loudness to which the stop is to be voiced, a chamber organ requires much thinner tongues in the reed stops than church organs. 3d, The curvature of the tongue, or the quantity of the opening between it and the reed: the more open it is, the louder, but generally, on that account, slower to speak. 4th, The smoothness and flatness of the edges of the aperture in the reed over which the tongue lies.

M. Biot, in his *Traité de Physique*, gives an account of some improvements made at Paris on reeds, and as they seem of great importance, we shall give a translation of the passage.

"I have been describing reeds such as are ordinarily used; but I am very happy in having it in my power to add to these notions the account of several remarkable improvements introduced into their construction by M. Grenié, an able amateur of music, who, by means of a modification equally simple and ingenious, has succeeded in removing their former faults, and in giving them new qualities.

"M. Grenié makes the reed AR, Fig. 2. Plate CCCCXLVI. of wood or copper, but with angles, and in the form of a parallelopiped. The tongue is a plate of brass (*laiton*,) perfectly plane, and cut in shape of a rectangle, so as to fill exactly, or almost exactly, the opening in front of the reed. A tuning spring, extremely firm and solid, *r r*, stops this tongue at the proper length, and fixes in an invariable manner the point from which it is to vibrate. Now, when this reed is fixed in the port-vent BCS, if one blows through the hole S, the compressed air, finding no issue, or hardly any issue, between the tongue and the sides of the reed, forces back the tongue, and makes its way. After a small quantity of air has passed, the natural elasticity of the tongue restores it to its original position, so that it again stops the passage of the air; but the velocity which it has acquired in thus returning, causes it also to pass that point, and it goes away from the reed in the opposite direction, pushing the air before it, till the resistance which it meets, joined to the effort of its elasticity, stops it, and brings it back to its original position; whence the air a second time forces it into the pipe. One understands that such oscillations, when they become sufficiently rapid, must produce a sound, as well as the beatings of the tongue on the ordinary reeds, but with this important difference, that the sound will have a quality incomparably more sweet, harmonious, and equal, since the plate of copper, instead of beating against wood, or copper, or skin, the resistance of which is always sudden and irregular, only causes a fluid perfectly homogeneous, compressible, and elastic, as air is, to recoil upon itself. Accordingly the reeds of M. Grenié have nothing of that rude and squalling sound which is disagreeable in ordinary reeds, and which does not altogether disappear even in instruments of which the reed is modified by the lips. Their sound, in the highest octaves as well as the lowest, is as sweet and as pure as that of mouth pipes; and ones sees that this must be the case from the manner in which the air is put into the vibratory motion.

"Another important point in M. Grenié's construction, is the firmness of the tongues, and of the tuning springs by which these are fixed. The strength of each tongue is combined with the breadth of the canal which it covers, in such a manner that the current of air can never give it several inflexions round its axis, and the fixedness of the tuning spring renders its length invariable, insomuch that, whatever be the force of the wind by which it is pressed, it can never octave. The increasing of the wind has no other effect than to render the oscillations of the tongue wider, and consequently, to swell the sound; and the musician regulates at his pleasure this swelling by means of a pedal, which moves bellows furnished with a spring. In this manner one can at pleasure produce sounds strong or weak, and pass from one of these extremes to the other by a *crescendo*, as regular and as sustained as that of the voice, or of instruments in which the sound is modified by the play of the lips.

"The air which causes the reeds to vibrate escapes by open tubes, increasing into a cone, and terminated in a hemisphere, D, Fig. 2. This enlargement gives the sound roundness and force. The length of each tube is always equal to that of the tongue. Experience has taught this proportion, as it has also the best shape of the tube.

"M. Grenié, in constructing his reed stops, was a long time arrested by a very singular phenomenon. He began with the lowest octave, of which C is unison, with an open mouth pipe of eight feet; and he had constructed a certain number of notes, by giving the wind to his reeds by port vents, or sockets of the same length, Fig. 3. But when he came to the first notes of the tenor, continuing to make his port-vents after the same manner, the reed did not speak at all. In vain he increased or diminished the wind, in vain he lengthened or shortened the tongue; the reed remained constantly mute, or gave only very bad sounds. At last, after many attempts, M. Grenié imagined that the length of the tube which brings the wind to the reed might have some unknown influence on its motion. He substituted for his fixed tubes two tubes, one sliding within the other, so that he could gradually vary the total length; and continued his trials till the reed gave a sound, brilliant, pure, and sustained. He found also, that, in order to obtain the tenor in its plenitude, it was necessary to make the port-vent much longer than for the note immediately preceding; and this length went on always diminishing for the more acute octaves, as represented in Fig. 1. Then the tops of his pipes formed the curve $T\,T'T''$. This seemed to indicate, that by prolonging this curve we should obtain the dimensions most favourable for the pipes of the first octave, which M. Grenié had at first made of equal length. But to his great astonishment, he found that there was absolutely no advantage in doing so; that, on the contrary, he came at last to have sounds very husky and dull, and irregular. He kept, therefore, with good reason, to his first construction, which yet he proposes to bring to perfection, by making his port-vents in future double and sliding, that he may be able to give to each the best length. He has since constructed on this model reed-pipes, which give the note of the sixteen foot open pipe, with a distinctness, a power, and a regularity truly remarkable. In this case the tongue is a plate of copper, the length of which is $0^{m}{\cdot}240$ (9.46 inches,) the breadth $0^{m}{\cdot}035$ (1.38 inches,) the thickness $0^{m}{\cdot}003$ (0 118 inch.) Its vibrations are so powerful, that they cause to tremble, the pipe, the port-vent, and every elastic body in the neighbourhood."

Having described the different kinds of organ pipes, we are now to show by what means the wind is conveyed to them. The reader will easily conceive that this will be greatly facilitated by each *stop* of pipes, that is, each scale, being in general disposed in ranges, as seen in Plate CCCCXLVI. Fig. 18. and Plate CCCCXLVII. Fig. 7. There are many exceptions to this general disposition, particularly with regard to the larger pipes, which are placed where room can be conveniently found for them, or for the sake of the external appearance of the organ, and the wind conveyed to them by means to be described. But the reader's conception of the machine will be greatly helped by keeping this general arrangement in view.

The first thing to be described is the *Sound-board*, which is indeed the main part of the machine. It is a box of greater or less extent, according to the size and contents of the organ, divided, by thin boards glued in it, into as many grooves as there are finger-keys; and as there are 12 finger-keys in each octave, the number of grooves is 12, multiplied by the number of octaves in the key-board These grooves run from the front to the back of the instrument, in order to carry the wind to the different stops or ranges of pipes, and lie parallel to each other between two horizontal planes. The distance of these horizontal planes, or the depth of the sound board, and the width of the different grooves, vary according to the number and size of the pipes that are at any time to be supplied with wind from each groove; that is, the depth of the sound-board of large organs, whose scales go very deep, and which have a great number of stops, is much greater than for smaller instruments; and the grooves which are to supply the lower part of the scale in all organs are widest, and become gradually narrower as the scale ascends. One of the chief defects found in old organs is, that sufficient allowance has not been made, especially in the larger stops, for this difference; so that the supply of wind is not sufficient.

Fig. 3. Plate CCCCXLVII. shows the under side of part of a sound-board. It is covered by parchment or leather AA, BB, (part of which is represented as rolled back to show the grooves which it covers,) except a space at BB, CC, along the fore part, left uncovered. In this space each groove is covered by a valve *a b*, *a b*, *a b*, by the London organ-builders technically called a pallet. Each valve, or pallet, has a spring which keeps it pressed on the aperture of the groove, and consequently excludes the wind; and to make the exclusion complete, or air-tight, the upper surface of the valve is covered with leather, levelled down very smooth. The valves are hinged at *a a a* by means of a piece of leather glued on them, and also to the parchment covering the under side of the sound-board.

The wind-chest is a box of such capacity as to receive all the valves; and that part of the sound-board forms the covering of the wind-chest. It is perfectly wind-tight, except at one opening communicating with the *main wind-trunk*, or *port-vent*. The front of the wind-chest is often divided into little pannels, removable at pleasure, that access may be had to the pallets, or valves, in case of need; but the better way is to screw on the front, which, though occasioning some more trouble when it is necessary to come at the valves, is yet on the whole preferable, as being more perfectly wind-tight, and less liable to be affected by variations in the dryness of the atmosphere. Fig. 1. AA, is the front of the wind-chest, opened to show the ends of the valves *g g g g*.

On the bottom of the wind-chest, and directly under the opening ends of the valves, is screwed a brass plate, running along the length of the chest, and pierced with small holes, through each of which passes a wire *f f f f*, &c. Fig. 1. completely filling the holes, but so as to slide easily up and down. These wires are the medium of communication between the finger keys and the valves. Formerly there used to be a little purse of bladder tied round each wire, which served to exclude the air, and allow the requisite motion; but the brass plate is found to be much better. The wires so completely fill the holes, that the loss of wind is so small as to be of no importance.

The *main wind-trunk*, or *port-vent*, is a large tube which receives the wind from the bellows, and conveys it up to the wind-chest; so that this last may be conceived as a horizontal continuation of the port-vent.

In former times, the bellows of organs were very much the same with the smith's bellows. Now-a-days they are always made to rise, keeping all the boards in the horizontal position. In Plate CCCCXLVII. Fig 5. is seen the end view of a small pair of bellows in a barrel-organ They consist of the *receiver* and *feeders*. The receiver is formed by two boards, the ends of which are *a a*, *b b*, which are connected together by the ribs *a a*, *c c*; *b b*, *c c*. These are thin boards, fixed by means of leather glued on them to the boards *a a*, *b b*. and to each other in the line *c c*. The side ribs are connected to the boards and to each other in the same way; and by leather glued on to the end ribs at the corners *c b*, *c a*, so that when air is forced in by the feeders, the higher board *a a* rises, keeping its horizontal position. The feeders are formed in the same way as the receivers, only that the side ribs are narrower at one end, on which they move after the manner of smiths' bellows. They receive the wind by a valve in the bottom of each, and force it into the receiver through similar valves in the lower board. The feeders are made to work alternately by the position of the cranks on the axle of the winder. In greater organs, the receiver of the bellows is double, and sometimes triple, as shown in Plate CCCCXLVI. Fig. 18. and Plate CCCCXLVII. Fig. 7.

The highest board of the receiver of the bellows is loaded with a certain weight, on the quantity of which, of course, the force of the blast depends, called the *weight* of wind. The receiver communicates by means of a short horizontal tube, to which it is connected by leather glued on, with the main wind-trunk or port-vent; this latter communicates with the wind-chest, which is closed by the front part of the sound-board with its valves. In Fig. 7. Plate CCCCXLVII. these parts are seen in their mutual connection; AA the bellows, BB the main port-vent, C the end of the wind-chest, open, to show *a*, the valve, with its spring *b*; DDD the end of the sound-board, the fore part of the bottom of which forms the top covering of the wind chest.

The upper side of the sound-board is of wood, of considerable thickness. It is planed, with the utmost care, to a perfect level. It is then divided into as many slips as there are stops belonging to the sound-board, which slips run lengthways of the sound-board, and consequently across the direction of the grooves. These narrow divisions or slips are formed by thin pieces of hard wood, called *bearers*, carefully planed straight, and of equal thickness throughout, and firmly screwed on the upper surface of the sound-board. Fig. 2. Plate CCCCXLVII. shows part of the upper surface of a sound-board, divided into four longitudinal slips by the bearers AA, AA. In these slips, holes are bored through the top of the sound-board, one into each groove. These holes are seen in the slip BB. They are in two lines, alternating, which is done in order to obtain a little more distance between the holes of the two adjoining grooves, in order to guard against *running of the wind*, which will be explained by and by, and for another purpose, which will appear immediately. Those holes, which are to give wind to the large pipes of the stop, are proportionally large, and they diminish as the scale ascends.

Over each slip or range of holes, lies *a register* or *slide*, CC, CC, which is generally of mahogany or wainscot, exactly fitting the slip, but in the slightest degree thinner than the bearers. The slide is pierced with holes, exactly corresponding to those in the sound-board. When it is drawn a little towards one end, it covers all the holes, and consequently all the pipes of that stop are deprived of wind. There is a little slit cut in some convenient part of the slide, which receives a strong iron pin fixed in the sound-board, and which just allows the requisite degree of motion in the slide to shut or open the holes as required. The slip on which the slide runs, and the slide itself, are laid over with black lead in water, which, when dry, leaves a glossy smoothness, and answers the same purpose as oil to metallic machinery. Sometimes the wind is apt to run along under the slide, and to blow into a different hole, which consequently causes a wrong pipe to speak; this is called *running of the wind.* To prevent this, little grooves are cut in the slips in the top of the sound-board, which run in a zig-zag line between the holes, as shown in the slip, BB, Fig. 2. Plate CCCCXLVII. These zig-zag little grooves conduct the superfluous wind out to the end of the slip, which remedies the evil.

Over the bearers and slides lie the *upper boards*, which receive the wind from the grooves through the slides, and on which the pipes are *planted*. The upper-boards are of stout stuff, planed perfectly level, and firmly screwed to the bearers, just allowing the registers to slide, but leaving as little space above them as possible consistently with that object. The larger stops especially, occupy much more room than to stand immediately over the grooves which are to supply them The wind is therefore conveyed to the place where the pipe can be conveniently planted. This is done in grooves cut in the upper-boards. The side of the upper-boards, which lies over the slides, is bored with holes exactly over those on the top of the sound-board. From these holes grooves are cut in the substance of the upper-boards open at the top-surface, to within an inch or so of the place where the pipe stands. There a hole is bored, and thence a communication made to the groove, leaving a little bridge. When all the grooves are cut in the upper-board, the surface is covered with parchment, which consequently shuts the grooves, making them canals for the wind, open only at the hole on the under side, which receives it from the grooves of the sound-board through the slide, and that on the upper side which receives the foot of the pipe. This last hole is counter-sunk at the mouth, and the foot of the pipe formed to be received neatly into it. In Fig. 7. Plate CCCCXLVII. EE, is the end of the upper-board, between which, and the sound-board DD, are seen the slides *c c c*, alternating with the bearers *d d d*. There is not room, however, for the larger pipes on the upper-boards: and they are therefore placed variously as most convenient, and the wind conveyed in metal tubes. Very frequently, in chamber organs especially, the feet of the larger pipes stand lower than the upper-boards, as Fig. 7. Plate CCCCXLVII. where the wind is conveyed to the great pipe G by the metal tube *f f f*.

The slides, which shut or open the stops, are put in the power of the organist by means of the *draw-stops g g g g*, Fig. 7. Plate CCCCXLVII. and Fig. 18, Plate CCCCXLVI. placed a little above the key-board on either hand. These draw-stops are connected with the slides by a very simple apparatus, of which an idea will be conveyed by one example. Fig. 7. Plate CCCCXLVII. H, is an upright roller which turns on its axis, the ends of which are received in the blocks at KK. To this roller the highest of the draw stops *g* is connected by a horizontal iron arm covered from the view by the roller, but of which the end is seen at *j*; *h* is a knee'd iron arm to the roller, the end of which is received into a hole in a block attached to the slide at *c*. This block, with the hole to receive the arm of the roller, is seen at *c*, Fig. 2. When, therefore, the draw-stop *g* is drawn towards the front of the instrument, it turns the roller H on its axis, which consequently, by its knee'd arm *h*, pushes in the slide *c*, and opens the holes in the sound-board and upper-board, and *vice versa.*

Besides the draw-stops, by which each single stop may be taken off or brought on, there is generally a *shifting movement*, which acts by a pedal to take off occasionally the louder stops, leaving only one or two of the softer for solo passages. This was formerly always effected by means of another set of slides under those for the draw stops, the mechanism of which will be easily conceived by the description already given. A more simple plan has been recently practised, which consists in merely adding a spring to each slide, to keep it in the position which opens the stop. The draw-stop being pushed in, to shut the pipes, falls into a check, which keeps it from returning till the organist pleases. The pedal shifting movement pushes in the slides of the stops, which it is to take off, and then returns of its own accord when the foot is removed.

In the Calcutta organ, which comprehends thirty-nine sounds in each octave, the key-board remaining the same as in others, the additional sounds are brought in, when required, by means of slides and sound-boards additional. Thus, over the first sound-board, which has twelve valves and as many grooves, there lies another sound-board with twenty grooves. A slide being acted on by a pedal, shuts the grooves B♭ and E♭, and opens A♯ and D♯; and so of the other extreme sharps and flats. See Music, Art. 22. *et seq.* After the same manner, by means of another set of grooves and slides, the acute and grave sounds are obtained in the upper part of the scale. But as so great a multiplication of the larger pipes would require too great room, all open pipes of more than four feet, and stopped pipes of more than two feet, are made grave or acute by means of shades, which are brought to the open end of open pipes, or to the mouth of stopped ones. These shades are on hinges, which are soldered on the pipe, and are acted on in classes by machinery and by pedals, which it is unnecessary to describe more minutely.

A view of the manner in which the finger key is connected with the valve of the sound-board is given in the section, Plate CCCCXLVII. Fig. 4. *a a* is the finger-key, moving on its centre pin *c*. *b* is a little rod of straight wood called a *sticker*, the lower end of which rests on the distant end of the finger-key. The other end of the sticker is attached by a pin to the end of a lever *d d*, moving on its centre at *e*. To the opposite end of the lever *d d* is attached the wire *f*, which passing through the brass plate on the bottom of the sound-board, is attached to the valve at *g*. When, therefore, the performer presses down the finger-key, the opposite end lifts the sticker, and consequently raises the end of the lever *d*, and this by the opposite end draws down the valve *g*. When the finger of the performer is removed, the spring *h* shuts the valve, and moves the lever sticker and finger-key, assisted by their own preponderance, to their original position. All this, however, supposes the finger-key immediately opposite the valve which it is to open, which cannot be the case with regard to much the greater number. The key-board occupies only the space of about three feet in the middle of the front of the largest organs; whereas the sound-board with its valves extends nearly the whole width of the front. Hence arises the necessity of still more machinery to connect the finger-key with the valve which it is to open. Plate CCCCXLVII. Fig. 1. shows this machinery. *a a*, *a a*, the finger-keys; *b*, *b*, *b*, *b*, stickers; *d*, *d*, *d*, *d*, levers as before; *m n*, *m n*, rollers moving on their axes; *l*, *l*, *l*, *l*, rods or wires attached to the ends of the levers *d*, *d*, *d*, *d*, and to arms in the rollers towards the end *m m*; *f*, *f*, *f*, *f*, the wires from the valves, attached to arms in the same side of the rollers, towards the distant ends *n n*; from which it is plain the valves will be opened by the pressure of the finger-keys.

The key-boards of organs are more or less extensive, and the most extensive is considerably less so than that of the piano-forte. There are three varieties principally in use. The most extensive, called the *long scale*, comprehends nearly five octaves, extending from GG, (two octaves and a half below middle C) up to F in Alt.; *i. e.* octave above F on the fifth line of the staff in the treble clef. In this key-board the lowest G♯ is usually omitted.

The *short scale* extends from CC (two octaves below middle C) up to the same F in Alt. In this scale, the lowest C♯ is usually omitted. The third variety is a kind of medium between these two, going down to GG by what is called a short octave; that is, there is a finger-key below CC, which, instead of BB, sounds GG, while the finger-key, which should, from its place, give CC♯, gives AA. By these two notes in the bass four keys are enriched, viz. that of G and that of C by the addition of the GG; that of A and that of D by the addition of the AA.

The pipes are planted on the upper boards, where they are fixed in a *rackboard*, which receives the feet, Plate CCCCXLVII. Fig. 7. LL; the apex of the cone being inserted into the upper boards, as already described. In planting, it is usual to place several of the great pipes belonging to the bottom of the scale at the right hand. In great organs the pipes are frequently planted alternately at either end, beginning from the bottom of the scale, which consequently throws each stop into two ranges, diminishing continually towards the middle of the instrument. The smallest stops are also generally placed toward the front, which serves the double purpose of giving a good view of the contents when the front is opened, and of allowing convenient access for tuning the instrument. In large organs the greatest metal pipes are disposed in the front, and gilded, so as to have an imposing effect.

Large organs have usually two or three key-boards, or *sets of keys*, as they are called, to each of which belongs its own set of stops, differently combined for variety of effect. Each key-board has its own wind chest, sound-board, and upper-boards. The key-boards are arranged one above another, and retiring like stairs. They have often, besides, pedal stops, consisting of two octaves, doubling the bass in the octave below. These pedal stops are played by the feet, by means of a set of pedals arranged after the same manner as the finger-keys.

The swell is a contrivance for enabling the performer to produce regular *crescendos* and *diminuendos*. In church organs it is a small organ belonging to one of the key-boards. To produce the swell, that part of the organ is inclosed in a box of thick wood, very close, which has the effect of softening the sound of the inclosed pipes. In old organs the front of the swell-box moves up and down like the sash of a window, by means of a pedal. As it opens more and more, the sound swells in a regular *crescendo* and *vice versa*. Messrs Flight and Robson of London have invented a very effective improvement on the swell. The front of their swell is composed of thick boards of five or six inches in breadth, each of which moves on an axis in the middle of its breadth. The edges of each board are bevelled away at an angle of 45°, so that these bevelled surfaces are parallel to each other. Each two contiguous boards overlap each other, the bevelled surfaces meeting, and the whole front is quite flush or even. The swell-pedal moves all the boards at once on their axes, and consequently opens immediately the interstices between the boards more or less, as they are brought nearer to the horizontal position or otherwise, Fig. 8. Plate CCCCXLVII. The bevelled surfaces are covered with leather, and therefore are very close. A very small opening makes an immediate burst on the ear, insomuch that a practised performer can imitate, not merely a regular *crescendo*, but *sforzato* notes, which were considered as peculiar to the bow of violins. At the same time, the ordinary swell can be equally well effected by the practised performer. This, it is acknowledged, is more difficult, but whoever has heard Mr. Flight himself, or Mr. Purkis, or Mr Adams, manage their swells, will make no question of their decided superiority. From the resemblance of the boards of this swell to Venetian window-blinds, Messrs. Flight and Robson call this a Venetian swell. Messrs. Wood and Small, of Edinburgh, make the front of their swells on something of the same plan, but with this difference, that their *Venetians* move on an axis at the upper edge of the board; nor do they overlap each other; and the edges are not bevelled away. The opening of the swell is thus more gradual than on Mr. Flight's plan, and consequently more easily managed; and, at the same time, it is more effectual than the old lifting sash. This is shown in Fig. 6. Plate CCCCXLVI.

In chamber organs the swell is often made of a small separate set of stops Where there is only one set of keys, it is supplied with wind from the sound-board by an upright set of grooves or sound-board, which again communicates with a horizontal sound-board; which has its slides and upper-board, and on which the stops are planted. Such a swell is seen in Fig. 18. Plate CCCCXLVII.

Messrs. Flight and Robson, however, usually inclose their chamber organs altogether in a Venetian swell, and they make them as effectual as the smallest, and without the inconvenience of the alteration in the pitch of the pipes in opening and shutting, to which small confined swells are subject.

We have described the different kinds of organ pipes, and shall now set down the different kinds of stops composed of them, that is, scales of pipes used in organs, with their distinguishing qualities or characters; and we shall arrange them under the same heads, of mouth-pipes open and stopped, and reed pipes.

I. *Stops of Open Mouth-Pipes.*

1. *Open Diapason.*—This is the fundamental stop of the whole instrument. It is made chiefly of metal; though sometimes the lowest octave is of wood, of which the quality in that part of the scale is much the same as that of metal pipes, but rather softer. The open diapason is voiced loud and round; that is, not reedy. Middle C is a two foot pipe The double diapason is a stop octave lower than the diapason, in order to double the bass. It contains two octaves, and is played by pedals.

2. *Dulciana.*—This is a metal stop unison with the diapason, consequently the pipes are of the same length, but of much smaller diameter; which gives them a very different quality. The diameter of the pipes is to the unison of the diapason about as 2 to 3. The dulciana is voiced extremely soft, and reedy in the tone. It is used chiefly as a solo stop, and is generally included in the swell. The lowest octave is very often made of wood stopped pipes.

3. *Principal.*—This is always of metal throughout. It is octave to the diapason, consequently the pipes are only half the length of those in the latter belonging to the same finger-key. Thus the pipe of the principal speaking by the finger-key middle C of the key-board is one foot, and when both draw-stops are out, middle C and its octave above are both heard. It is rather of smaller diameter than the unisons in the open diapason; and is voiced rather softer, and with a reedy quality of tone.

4. *Dulciana Principal.*—A metal stop throughout. Unison with the principal, but on a smaller diameter of pipes, and voiced in the same manner as the dulciana diapason.

5. *Fifteenth.*—This, as its name implies, is double octave above the diapason, and consequently octave above the principal; and the pipes are only half the length of those of the principal that speak by the same finger-keys. It is voiced after the same manner as the principal, or rather softer. It is always metal throughout.

It is not difficult to understand that these stops playing together should have a good effect; this being only doubling the parts in the octave and double octave; but it is not so easy to comprehend how the next stops can be admitted.

6. and 7. *Twelfth and Seventeenth Major.*—These, as their names signify, are the octave fifth above the diapason and double octave third major to that stop, or fifth to the principal, and major third to the fifteenth. These two stops are voiced much like the principal.

At first sight, it seems contrary to every idea of good harmony, that every note in the bass should be accompanied by its fifth in a continued part, as it were, running parallel with it; and if we consider, besides, that when the twelfth and seventeenth are used with the other stops, every note of a chord has its twelfth and seventeenth, which are quite discordant among themselves, we should suppose that these stops could produce nothing but jargon. But when these stops are not voiced too loud, and used with the diapasons principal and fifteenth, the compound sound to each finger-key is felt as one only, with a degree of reediness which mouth pipes do not otherwise possess. The seventeenth ought, however, to have a twenty-second or octave fifteenth over it; otherwise it is too remarkable, and becomes offensive.

The theory of these stops, therefore, seems to be deducible from the well known and very remarkable property of musical sounds producing their twelfth and seventeenth major, insomuch that some have said that there is hardly such a thing as a simple sound in nature. The stops in question may thus be regarded as merely making the natural harmonies, implied in every musical sound, more audible.

The 12th and 17th are tuned perfectly true to the diapason and principal, and this is an additional source of harshness in the ordinary scale of organs; because these stops are out of tune with the tempered fifths and thirds of the scale. But, in the Calcutta enharmonic organ, where the whole scale is tuned perfectly true without temperament, these stops, (the twelfth and seventeenth,) produce a very fine effect. They add great richness and reediness, and produce an effect so like that of trumpets and oboes, that experienced organists were deceived into the belief that such stops were really speaking.

This effect of the harmonics to the fundamental sound is a very curious fact, and seems to let in a ray of light respecting the cause of the peculiar character of reeds, and therefore seems well worth the attention of the philosopher.

II. *Stops of Shut Mouth-pipes.*

Shut, or stopped pipes, in general, have a quality quite different from that of open pipes. They are voiced to a round quality, the opposite of reediness, and approach a little towards a nasal sound. They are used to counteract the thinness attending too much reediness, and to bind together the different qualities of the other stops.

1. *Stopped Diapason.*—This is unison with the open diapason. The pipes speaking by the same finger-key are only half the length of the open, and are of smaller diameter, about as 2 to 3. The stopped diapason is always of wood up to middle C; above that metal, and generally with chimney-tops. Large stopped pipes of metal are not good; but from middle C upwards are good, flutey, and clear; and therefore preferable to wood in that part of the scale.

2. *Flute.*—This is unison with the principal, and is voiced soft and flutey. The lower part, up to one foot C, *i. e.* octave below C of the key-board, is of wood; the higher octaves metal.

III. *Reed Stops.*

The peculiar character of reeds is well known. They give brilliancy, richness, and decidedness, which can hardly be obtained in the same degree otherwise. One of the great niceties of the organ-builder's art, is to bring his reeds to a good quality.

1. *Trumpet.*—The form of which is shown in Plate CCCCXLVI. Fig. 6. This is unison with the diapasons. The quality ought to be full, and as round as possible. In large organs the trumpet stops go throughout the scale; in smaller organs often no lower than middle C.

2. *Clarion*, or *Octave Trumpet.*—It is of the same form as the trumpet, and voiced to a similar quality. It is only used when great brilliancy is required.

3. *Oboe*, Fig. 11.—This is unison with the diapasons. It is voiced very soft, and as like the real instrument of the same name as possible. It is reckoned in this country the chief reed stop. It is used for solo passages. It bears the same relation to the trumpet that the dulciana does to the open diapason. Its scale is from F, the clef note of the bass, to the top.

4. *Cromorna*, Fig. 12.—This is also unison with the diapasons. It is voiced soft like the oboe, but its quality is very different. It is tubby, and bears to the oboe the same relation as the stopped diapason to the open.

5. *Bassoon.*—Also unison with the diapasons. It is voiced extremely thin. Its quality is rather harsh. It is used to give reediness to the choir organ.

6. *Vox Humana*, Fig. 4.—Unison with the diapason. This is a stop of a very peculiar quality; something like a bad human voice; like an old woman singing. The reed is much muffled, and as it were smothered in a box. It is never used by itself, but with one of the diapasons in the choir organ: The two together bring out something like the voice.

IV. *Compound Stops.*

Besides the single stops which have been enumerated, there are compound stops, which are made of mouth pipes, and are used to give strength to the great organ. These are,

1. *The four-rank Sesquialtra.*—This is made entirely of open metal pipes. It consists, as its name imports, of four ranks of pipes speaking from the same wind. These are the 17th; octave 12th, or 19th; the 22d, or double octave; and the 24th, or octave 17th, all as reckoned from the diapason. This stop extends throughout the whole scale; that is, to the lowest finger key of the scale, the sesquialtra gives the four sounds enumerated, and so to every note in the scale, till the pipes become very small; that is, less than an inch and a half. Then each part *breaks* to the octave below. There is no rule about this breaking, except that no more than one rank is to break at a time.

2. *The five-rank Cornet.*—The ranks are the stopped diapason of wood, principal, 12th, 15th, and 17th—all made of a very large diameter, and voiced as loud as possible. The more noise the more honour to the organ-builder and organist.

3. *The three-rank Mixture.*—The ranks are the 24th, or octave 17th, which breaks to the principal. The 26th, or double octave 12th, which breaks to the 12th; and the 29th, or double octave 15th, which breaks to the 15th.

We shall conclude this account of this most grand instrument, by a summary of what stops are usually contained in the largest cathedral organs in England.

There are three sets of keys, viz. one for the great organ—one for the choir organ—and one for the swell.

I. *Great Organ.*

Middle set of keys. The key-board contains nearly five octaves from GG (twelve foot open pipe) to F in Alt. Its stops are from twelve to fifteen or sixteen in number; viz. one double diapason of two octaves from GGG, (24 feet) to 6 feet G, played by finger or pedals. 2d. Two, and sometimes three open diapasons, all of metal. 3d, A stopped diapason, metal chimney topped from middle C; wood below. 4th, One or two principals; metal throughout. 5th, Twelfth, ditto. 6th, Fifteenth, ditto. 7th, Seventeenth or tierce, ditto. 8th, A four rank sesquialtra throughout. 9th, Five rank cornet from middle C upwards. 10th, Three rank mixture throughout. 11th, Trumpet throughout; sometimes two trebles. 12th, Clarion or octave trumpet.

II. *Choir Organ.*

Lower set of keys. Scale the same as great organ.

The choir organ generally contains eight or nine stops. 1st, Small open diapason. This is metal from gamut G to the top of the scale; wood stopped pipes below. 2d, Dulciana, ditto, ditto. 3d, Stopped diapason the same as in the great organ. 4th, Principal. 5th, Dulciana principal; this is sometimes omitted.

6th, Flute. 7th, Fifteenth. 8th, Cromorna from octave below middle C of the key-board. 9th, Bassoon throughout.

III. *Swell.*

Highest set of keys. Scale from F on the fourth line of the bass to F in alt.

The swell usually contains seven stops. 1st, Open diapason. 2d, Dulciana. 3d, Stopped diapason. 4th, Principal. 5th, Three-rank cornet; the stopped diapason and principal being omitted. 6th, Trumpet. 7th, Oboe.

The barrel-organ is an organ which is played on by machinery, instead of the fingers of a performer. Its construction is the same as that above described, except that for the key-board is substituted a set of levers which are raised and kept up the requisite time, by means of little brass pegs disposed on the surface of a cylinder. The turning of the cylinder on its axis, with an equable motion, measures the time, and the pegs being disposed on the circle described by points, on its surface, and duly proportioned to the whole circumference, keep open the valves of the sound-board, during the time each pipe should speak. Fig. 5. Plate CCCCXLVII. is the section of a small barrel-organ. AA, section of the barrel or cylinder, on the axle of which is fixed a toothed wheel B, in the teeth of which a screw on the axle D, turned by the winder C, works, and consequently turns the cylinder. On the circumference of the circle are represented the pegs, one of which keeps up the lever *e g*, moving on the axis *f*. The end *g* of the lever pushes down the sticker *h*, which, by a wire passing into the wind-chest, opens the valve *j*. Suppose on this barrel an air of thirty-two bars were to be set, and conceive the circumference of the circle divided into so many equal parts, these parts will represent the bars or measures of the air; and being occupied with the due proportion of pegs and blanks under the proper levers, will, by the turning of the cylinder, make the proper pipes speak at their right times. As the levers for opening the valves are at considerable distance, and the pegs occupy very little space, there is room for several airs being set on the same barrel. This being pushed a little way towards one side, till the pegs of another tune are brought under the levers, is there fixed, by means of a sliding bolt, which falls into a notch, in a piece of brass fixed to the frame in which the barrel runs. When pieces of music are to be set on a barrel longer than one revolution could afford space for, the end of the axle of the cylinder is formed into a screw, which works on a fixed pin, and consequently draws the barrel horizontally, while turning round its axis. The pegs are then disposed in spiral lines round the surface, so that those of the first revolution are clear of the levers, when those of the second come to them. Thus as many revolutions are obtained as are necessary.

Organs are frequently constructed so as to be capable of being played either by the finger or by barrels. This is generally effected by two sets of valves to the same sound-board in the same wind-chest. Many ingenious instruments of this kind have been constructed by Messrs. Flight and Robson, in which different organs are combined in order to give the accompaniments in their true place in the scale. The most remarkable instrument of this kind in England, and perhaps in Europe, is their **Apollonicon**, which is exhibiting every day in London.

The external dimensions of this instrument are 19 feet wide, 15 feet deep, and 24 feet high; its mechanical performance is produced from the revolution of three cylinders, of two feet in diameter each, two of them eight feet long, and the third four feet long; these act upon the whole musical powers of the instrument, commanding by one of them a scale of eight octaves, viz. the whole of the powers of the great or principal organ from GG up to G in Alt. five complete octaves, and an accompaniment or separate organ of three complete octaves from tenor of fiddle G up to G in Alt.; the second cylinder acts upon two other scales of three complete octaves each, one from tenor of fiddle G up to G in Alt.; and the other from gamut G up to G, above the staff, treble cleff; the third cylinder acts upon the pedal notes or lowest bass of the instrument of two complete octaves from CCC up to C above gamut. From the same cylinder the swells of the instruments are acted upon, of which there are four; one to the great organ, and one each to the accompaniment organs before mentioned. There are in the whole instrument 46 stops, which are acted upon individually by a peculiar mechanical action, applied to as many keys from the cylinders, by which an instantaneous change or combination of stops is commanded, expressive of the effect of oboes, flutes, clarionets, trumpets, or other instruments, according to the nature of the piece of music performing. The pieces of music already set upon the cylinders, (two setts,) are Cherubini's overture to Anacreon, Mozart's overtures to Zauberflote, and La Clamenza di Tito, Handel's introduction to the Dettingen Te Deum, and Haydn's military movement from his twelfth grand symphony.

The whole powers of the instrument can also be brought into action by manual performance; to effect which there are five key-boards or sets of finger-keys. The first, or principal set, has five complete octaves from GG up to G, as before described, to which there are twenty-two stops, with three pedals for decreasing the power, one taking off the reeds, the second the compound stops, and the third the diapasons, leaving on only the dulciana; the whole inclosed in a Venetian swell. There are also, for the feet of the performer, at the same set, two octaves of pedals, from CCC up to C above gamut. The second and third sets of keys command an accompaniment organ of three octaves each, from fiddle G up to G, each possessing eight stops, and inclosed in a Venetian swell, from which the effects of flutes, oboes, &c. &c. may be produced. The fourth set has three octaves from gamut G up to G above the staff of the treble cleff, and has six stops inclosed in a swell, from which the effect of horns, trumpets, bassoons, &c. can be given. The fifth set of keys has a compass of two octaves, from CCC up to C above gamut, acting upon the pedal pipes, thus enabling another performer to give any rapid passages which the feet of the performer at the principal set of keys could not possibly execute; this set of keys has two stops, the pedal diapason and a reed stop. The effect capable of being produced by five performers on the instrument, by a previous arrangement of the music in parts, is very grand and interesting. The largest pipe in the instrument is 18 inches over, by 16 feet long.

GENERAL EXPLANATION

OF THE

PLATES BELONGING TO VOLUME FOURTEENTH

OF THE

AMERICAN EDITION

OF THE

NEW EDINBURGH ENCYCLOPÆDIA.

PLATES CCCCI. CCCCII. CCCCIII.

These Plates, from the elegant pencil of R. K. Greville, Esq. are illustrative of the subject of Mosses, and are minutely explained in the article Musci.

PLATE CCCCIV.*

Contains a Table of the Compass of Voices and Instruments.

PLATES CCCCIV. CCCCV.

Contain Diagrams illustrative of the Theory and Practice of Navigation.

PLATE CCCCVI.

Fig. 1. Is a section of a Stone Wear, by Smeaton.
Fig. 2. Is a section of a Wooden Wear with Sluices, on the River Wittigra in Russia.

PLATE CCCCVII.

Represents the Inclined Planes used in Canals in Italy.

PLATE CCCCVIII.

Contains Diagrams illustrative of Canal Cutting, Canal Boats, &c.

PLATE CCCCIX.

Figs. 1—6. Represent a Single Lock, on the Languedoc Canal.
Fig. 7. Is a Circular Lock at Agde.
Figs. 8, 9. Are a Section and Plan of the Canal at Burgundy.

PLATE CCCCX.

Fig. 1. Represents one of the Locks in the Caledonian Canal.
Figs. 2—7. Represent Locks and Lock-Gates at Ellesmere and Forebay.

PLATE CCCCXI.

Fig. 1. Represents a Lock on the Wittigra.

PLATE CCCCXII.

Contains a View of the Reservoirs of St. Ferriol and Lampy.

PLATE CCCCXIII.

Contains a view of the Reservoir at Glencorse, near Edinburgh.

PLATE CCCCXIV.

Figs. 1, 2. Represent the Aqueduct de Cesse on the Languedoc Canal.

Figs 3, 4. Show the Kelvin Aqueduct on the Forth and Clyde Canal.
Fig. 5. Represents the Aqueduct over the River Lune, at Lancaster.

PLATE CCCCXV.

Figs. 1—8. Represent Chirk Aqueduct, on the Ellesmere Canal, designed by Thomas Telford, Esq.
Figs. 2—7. Represent the great Aqueduct of Pontcysylte, at the bottom of Llangollen Valley, on the Ellesmere Canal, designed by Thomas Telford, Esq.

PLATES CCCCXVI. CCCCXVII.

Contain a View of a Wooden, and also of a Cast Iron Moveable Bridge, &c

PLATE CCCCXVIII.

Fig. 1. Is an elevation of a Skewed Bridge at Blackhall, near Paisley.
Figs. 2—13. Are Diagrams illustrative of the theory of Skewed Bridges.

PLATE CCCCXIX.

Contains Specimens of various Stop Gates and Let Offs.

PLATES CCCCXX. CCCCXXI. CCCCXXII. CCCCXXIII

Contain Representations of Coins and Medals illustrative of the Article Numismatology.

PLATES CCCCXXIV. CCCCXXV. CCCCXXVI.

Contain Figures illustrative of the Articles Observatory and Odometer.

PLATE CCCCXXVII.

Fig. 1. Cerastes Vulgaris.
Fig. 2. Trigonocephalus Lanceolatus.
Figs. 3—6. are illustrative of the Anatomy of Serpents.

PLATES CCCCXXVIII. CCCCXXIX. CCCCXXX.

Contain Diagrams illustrative of the Theory of *Dioptrics*.

PLATE CCCCXXXI.

Figs. 1—7. Illustrate the Huygenian Theory of Light.
Figs. 8—23. Illustrate the Theory of *Catoptrics*.

PLATE CCCCXXXII.

Figs. 1—12 Illustrate the Theory of *Catoptrics*.
Figs. 13—20. Illustrate the Doctrines of *Chromatics*, or the Colours of Light.

PLATE CCCCXXXIII.

Fig. 1. Represents the Spectrum, according to Sir Isaac Newton.
Fig. 2. Is the Spectrum, according to Dr. Wollaston.
Figs. 3, 4. Illustrate the Cause of the Imperfections of Refracting Telescopes.
Figs. 5—9. Represent Dr. Brewster's Instrument for measuring Dispersive Powers.
Figs. 10—14. Illustrate the Doctrine of the Secondary and Tertiary Spectrum.
Fig. 15. Is a Diagram for explaining Fraunhofer's Experiments.
Fig. 16 Represents the Spectrum, with all the Lines and Bands discovered by M. Fraunhofer.
Fig. 17. Is the Law which represents the Intensity of Light at different Points of the Spectrum.
Figs. 18—28. Are Diagrams illustrative of the Inflexion of Light, the Colours of Thin Plates, and Dr. Young's Law of Interference.

PLATE CCCCXXXIV.

Represents the singular Spectra discovered by M. Fraunhofer, as produced by Inflected Light.

PLATE CCCCXXXV.

Figs. 1—4. Illustrate Sir Isaac Newton's Theory of the Colours of Thin Plates.
Fig. 5. Illustrates Dr. Young's Explanation of the Colours of Thin Plates.
Fig. 6. Is a Diagram for explaining the Doctrine of Thick Plates.
Figs. 7—9. Illustrate Dr. Brewster and Mr. Knox's Experiments on the Colours of Double Plates.
Figs. 10—12. Illustrate Dr. Young and Dr. Brewster's Experiments on the Colours of Mixed Plates.
Figs. 13—19. Are Diagrams illustrative of the Doctrine of Double Refraction.
Figs. 20—23. Illustrate the Doctrine of the Polarisation of Light.

PLATE CCCCXXXVI.

This Plate illustrates the Doctrine of the Polarisation of Light, and of the various Phenomena of Crystallized Bodies produced by their action upon Polarised Light.

PLATE CCCCXXXVII.

Figs. 1—3. Represent the Phenomena of Bent Glass when exposed to Polarised Light.
Figs. 3—9. Represent the Phenomena of Apophyllite when exposed to Polarised Light.
Figs. 10—13. Illustrate the Theory of the Multiplication of Coloured Images in Iceland Spar.
Figs. 14—15. Explain the Theory of Double Refraction and Polarisation.
Figs. 16—19. Show the phenomena seen by exposing the Crystalline Lens of Fishes, &c. to Polarised Light.
Figs. 20—23. Are Diagrams explanatory of the Rainbow.

PLATE CCCCXXXVIII.

Figs. 1—6. Phenomena of Unusual Refraction observed by Dr. Vince at Ramsgate.

Figs. 7—12. Diagrams Illustrative of Dr. Wollaston's Theory and experiments on Unusual Refraction.
Figs. 13, 14. Representation of the singular Phenomena of the Apparent Transference of Dover Castle to the other side of the hill between it and Ramsgate, as observed by Dr. Vince.
Figs. 15, 16. Diagrams illustrating M. Biot's results respecting Unusual Refraction.
Fig. 17. Phenomena of Unusual Refraction, observed in the Greenland Seas, by Captain Scoresby.
Fig. 18. Shows Bouguer's method of measuring the Intensity of different Lights.
Figs. 17—22 Are Illustrative of Lambert's method of measuring the quantities of Light reflected and transmitted by one or more surfaces.

PLATE CCCCXXXIX.

Fig. 1. Is the Multiplying Glass.
Fig. 2. Theory of the Common Looking Glass.
Figs. 3, 4. Pyramidal Prism for combining into one image the separate parts of an object.
Fig. 5. Shows the Effect of Cylindrical Mirrors.
Fig. 6. Explanation of the Camera Obscura.
Fig. 7. Portable Camera Obscura.
Fig 8. Portable Camera Obscura for Drawing.
Fig. 9. Lenses for making the Image erect in the Camera Obscura.
Fig. 10. Camera Obscura for Public Exhibition.
Figs. 11, 12. Represent the Magic Lantern and the Arrangement of its Lenses and Mirror.
Fig. 13. Represents an Arrangement for a Phantasmagoria proposed by Dr. Young.
Fig 14. Theory of the Single Microscope.
Figs. 15, 16. Theory of the Compound Microscope.
Fig. 17. Astronomical Telescope.
Fig. 18. Galilean Telescope.
Fig. 19. Terrestrial Telescope.

PLATE CCCCXL.

Fig. 1. Gregorian Telescope.
Fig. 2. Cassegrainian Telescope.
Fig. 3. Newtonian Telescope.
Figs. 4, 5. New Reflecting Telescope proposed by Dr. Brewster.
Fig. 6. Double Achromatic Object-Glass, according to Mr. Herschel's Formulæ.
Figs. 7, 8, 9, 10. Represent the combinations for Achromatic Fluid Object-Glasses, used by Dr. Blair.
Figs. 11. 12. Represent Mr. Ramsden's Dynameter.
Figs. 13, 14. Represent the Dynameter as improved by Mr. Jones.
Figs. 15, 16, 17, 18. Represent different combinations of two lenses placed together for correcting the Spherical Aberrations according to Mr. Herschel.

PLATE CCCCXLI.

Represents Sir William Herschel's Large *Forty Feet* Telescope.

PLATE CCCCXLII.

Fig. 1. Achromatic Eye-piece, with *Two* Glasses.
Fig. 2. Do. with *Three* Glasses.
Fig. 3. Do. with *Four* Glasses.
Fig. 4. Ramsden's Eye-piece.
Figs. 5, 6 7, 8. Represent Dr. Wollaston's Method of centering a Triple Object-Glass.
Figs. 9, 10, 11. 12. Represent different forms of the Dichroscope.
Figs. 13, 14. Is the Optigraph of Mr. Ramsden, as improved by Mr. T. Jones.
Fig. 15. Is Dr. Brewster's Teinoscope.
Figs. 16, 17. Represent Dr. Wollaston's Instrument for measuring Refractive Powers.
Figs. 17, 18. Represent Dr. Brewster's Chromatic Thermometer.
Figs. 20—26. Represent the principles and Construction of Dr. Thomas Young's Improved Optometer.

PLATES CCCCXLIII. CCCCXLIV. CCCCXLV.

Contain Figures illustrative of the Article ORDNANCE.

PLATES CCCCXLVI. CCCCXLVII.

Contain Figures illustrative of the Article ORGNA

END OF VOLUME FOURTEENTH.

William Brown, Printer, Philadelphia.

MUSCI. PLATE CCCCI.

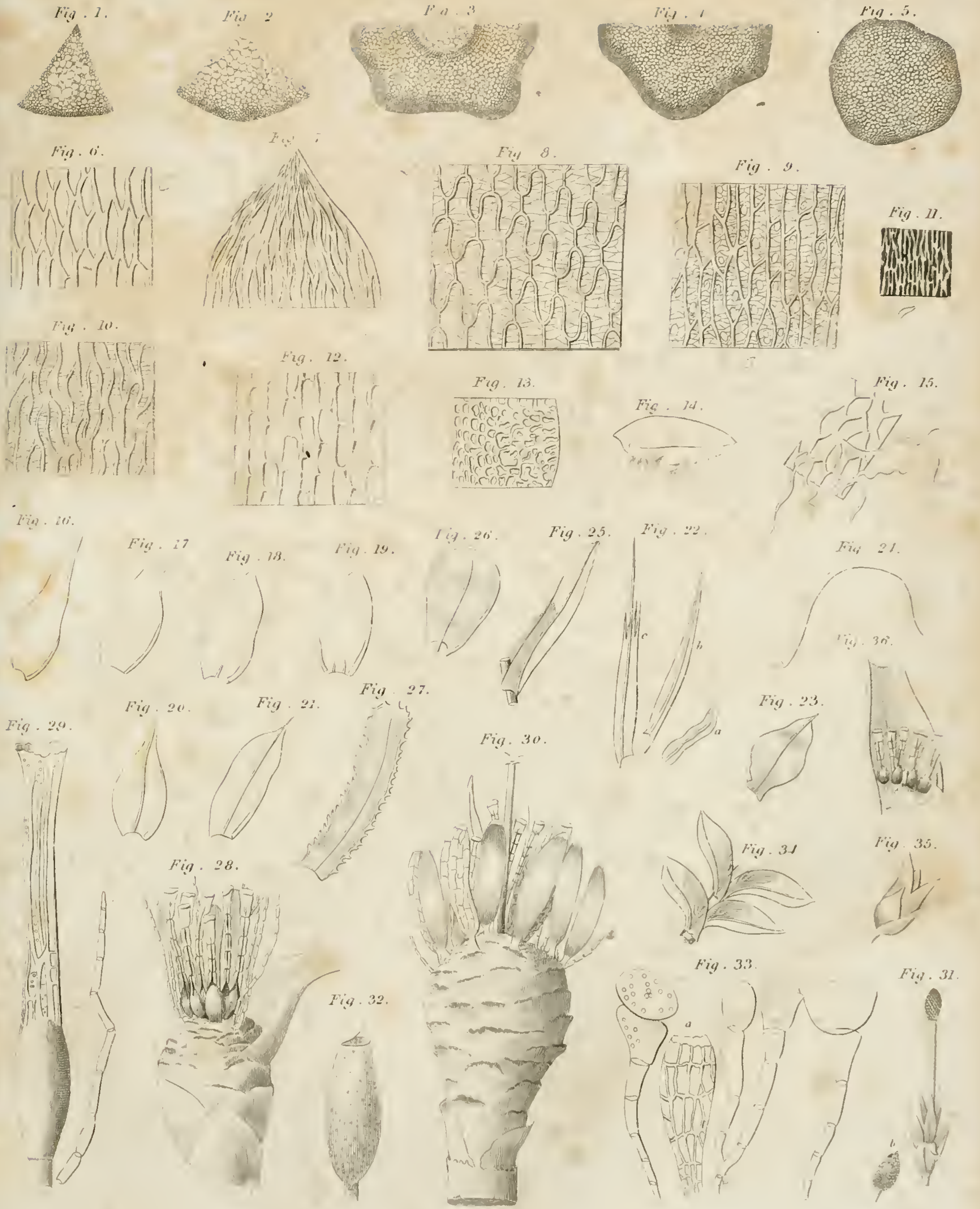
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Fig. 19.
Fig. 26.
Fig. 25.
Fig. 22.
c
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Fig. 24.
Fig. 36.
Fig. 29.
Fig. 20.
Fig. 21.
Fig. 27.
Fig. 23.
Fig. 30.
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Fig. 34.
Fig. 35.
Fig. 32.
Fig. 33.
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Fig. 31.
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MUSCI. PLATE CCCCII.

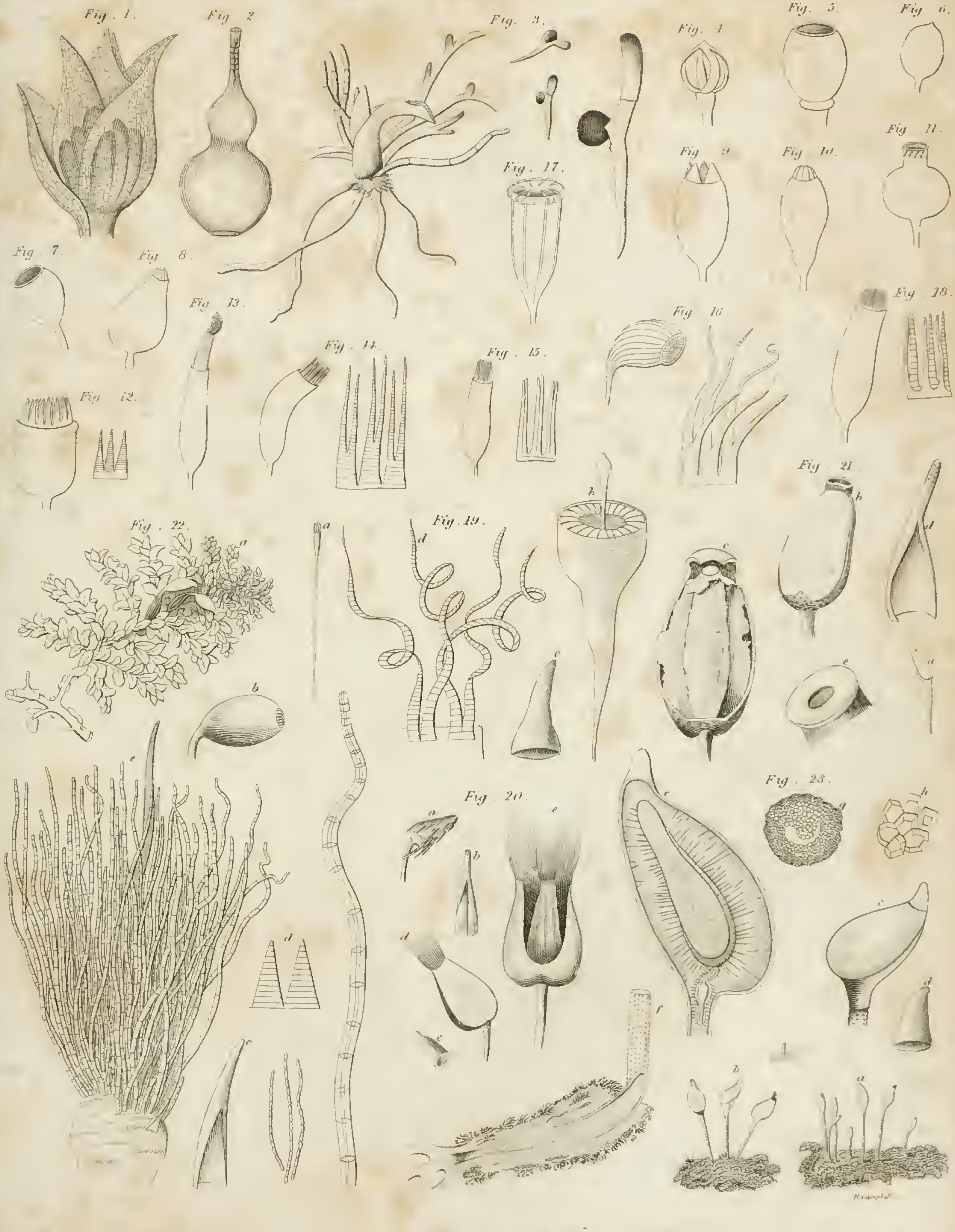

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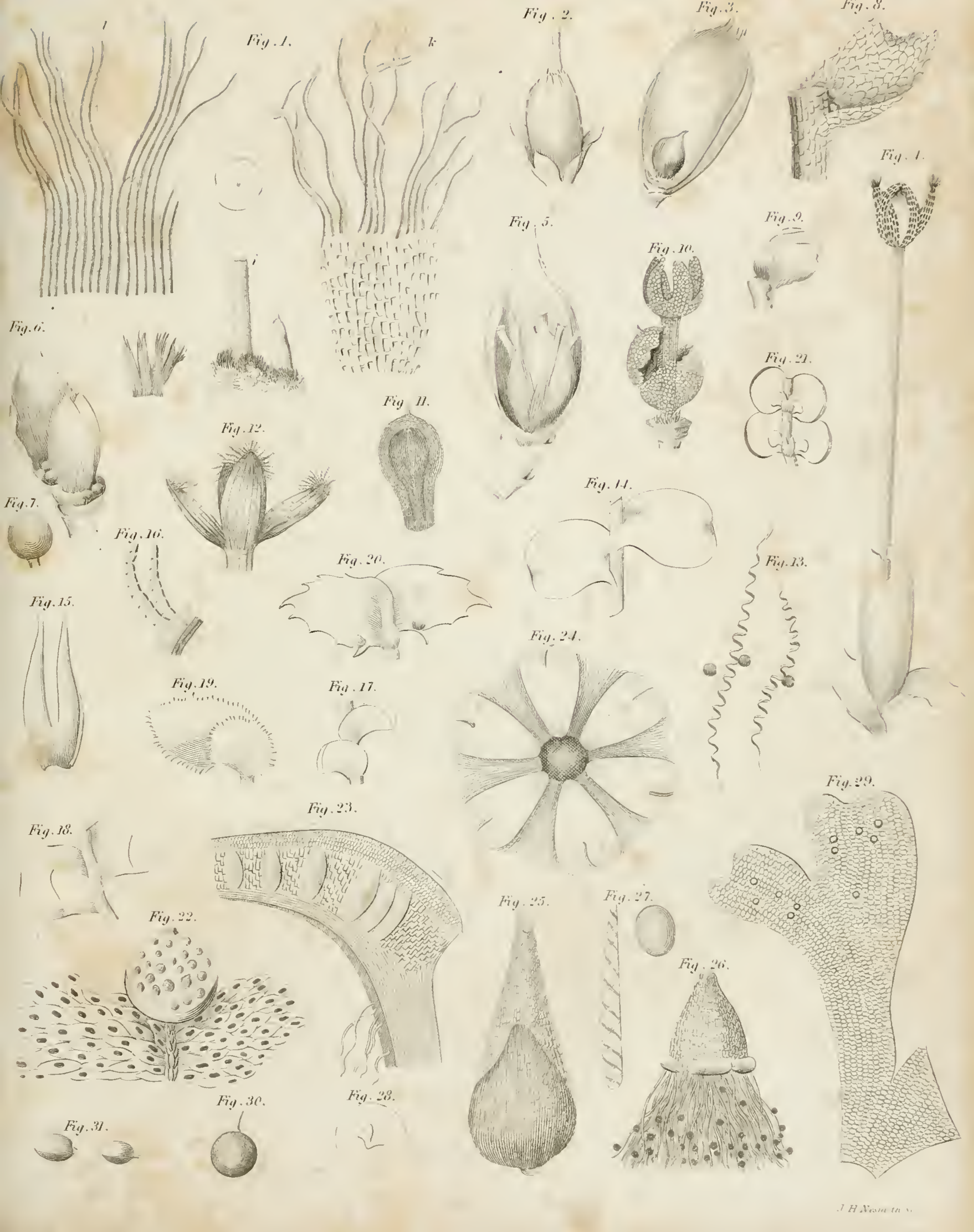
PLATE CCCCIII.

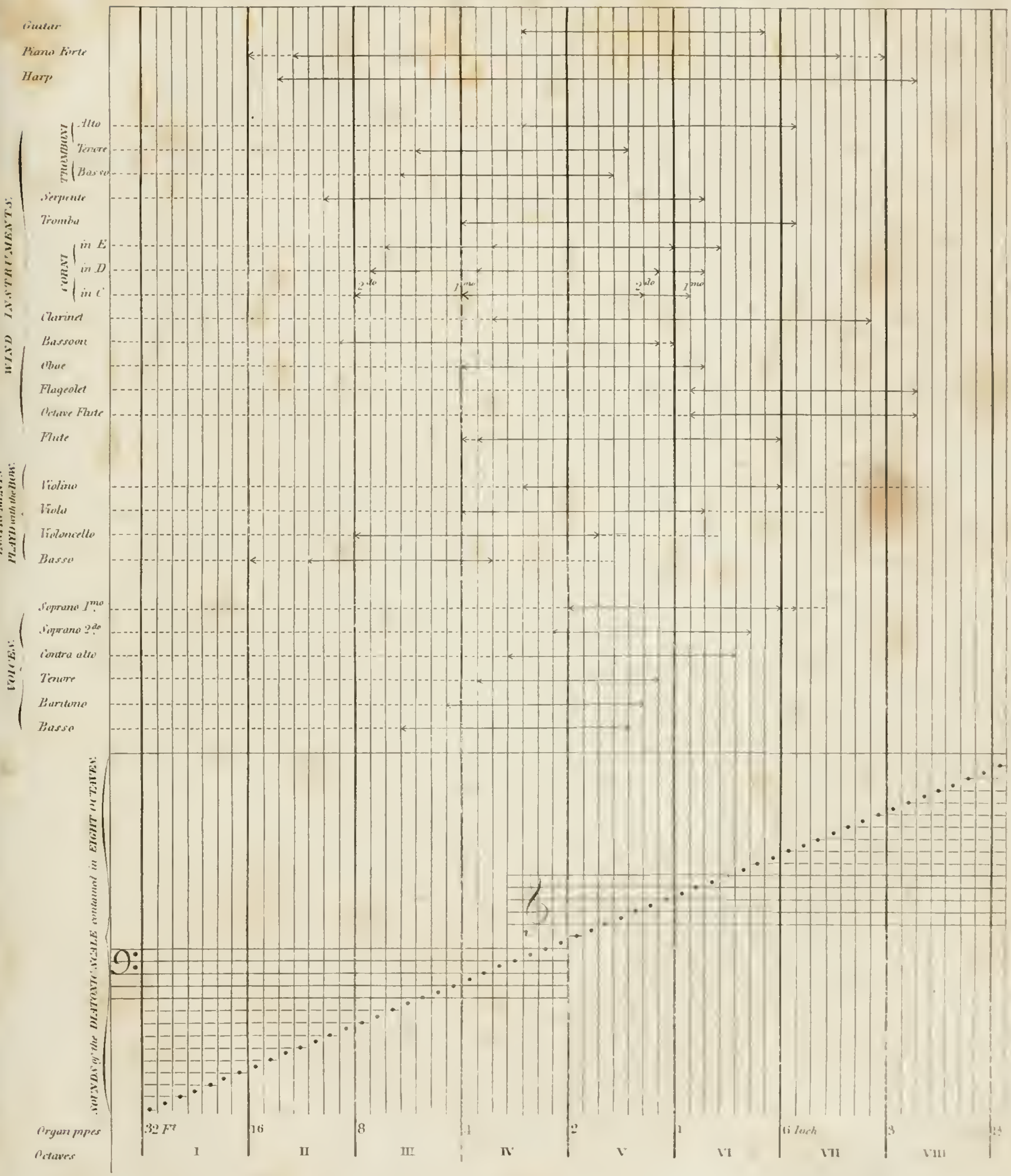


J. H. Nasmyth sc.

MUSIC.

PLATE CCCCIV.

TABLE of the COMPASS of VOICES and INSTRUMENTS, SHEWING the PLACE EACH OCCUPIES in the SCALE.



NAVIGATION, *PLATE CCCCV.*

Fig. 1.

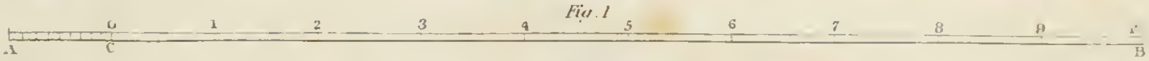


Fig. 2.

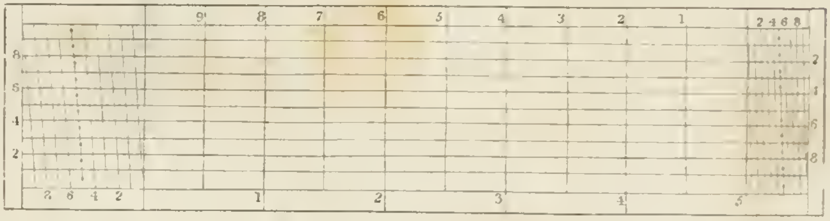


Fig. 3.

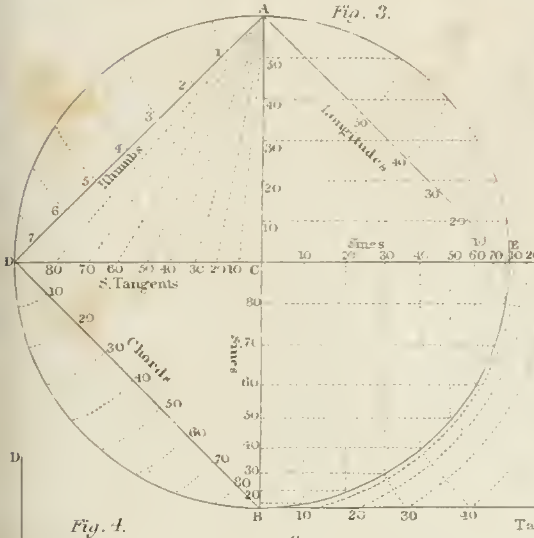


Fig. 12.

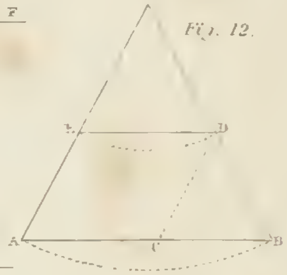


Fig. 4.

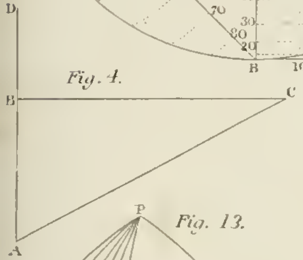


Fig. 5.

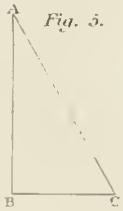


Fig. 6.

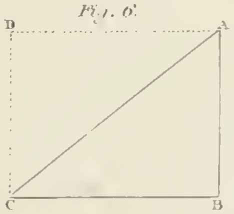


Fig. 7&8.

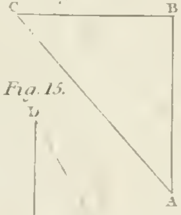


Fig. 11.

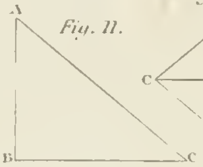


Fig. 17.

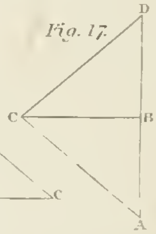


Fig. 16.

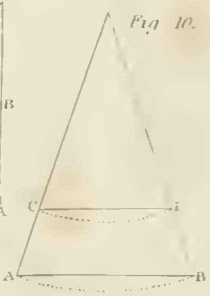


Fig. 13.

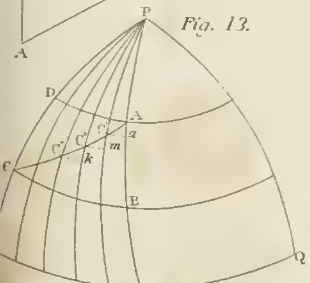


Fig. 15.

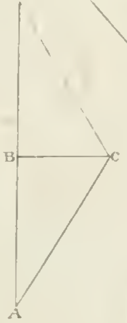


Fig. 9.

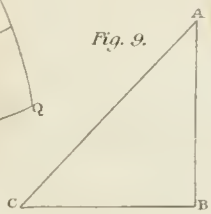


Fig. 22.

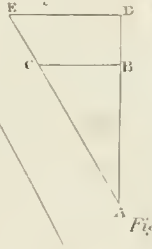


Fig. 10.

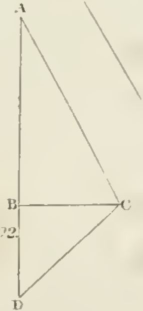


Fig. 14.

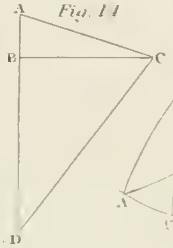
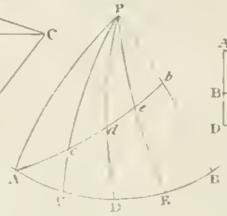


Fig. 18. page 197.



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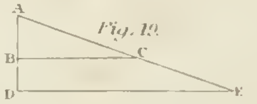
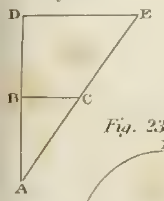


Fig. 20.



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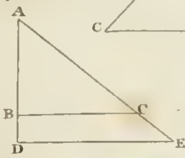


Fig. 23.

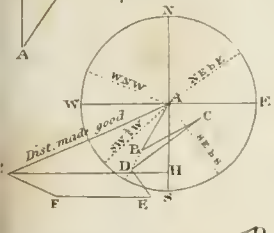


Fig. 24. page 202.

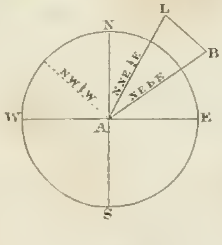


Fig. 25. page 202.

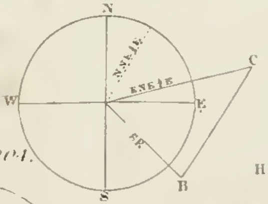


Fig. 31.

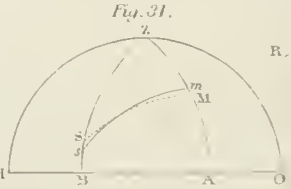


Fig. 28. page 205.

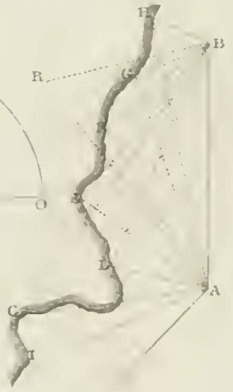


Fig. 27. page 204.

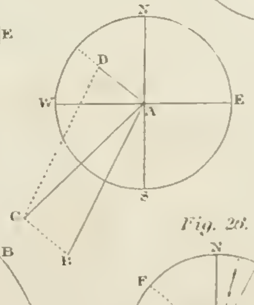
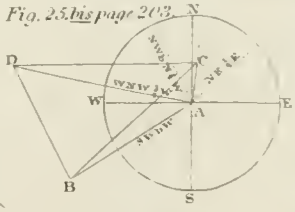


Fig. 25. bis page 203.



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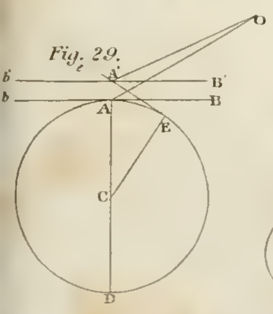

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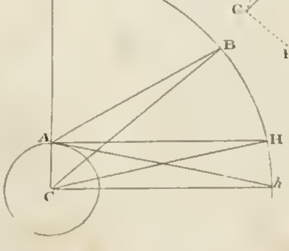

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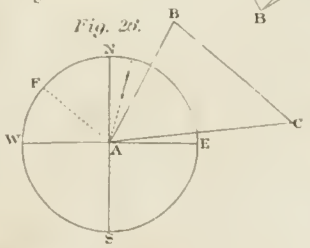
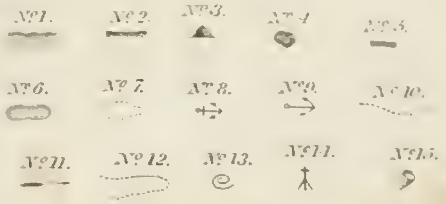




[illegible] Sc.

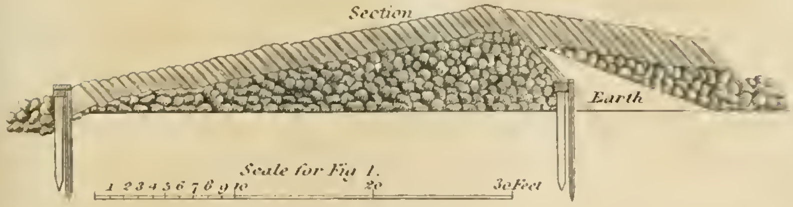
NAVIGATION INLAND. *PLATE CCCCVI.*

WEARS

Fig 1.

Wear Constructed by Mr Smeaton on the River Carron

Section



Plan

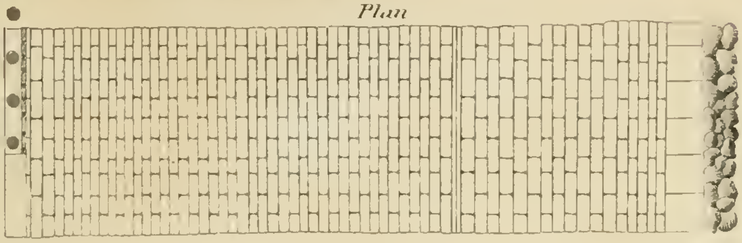
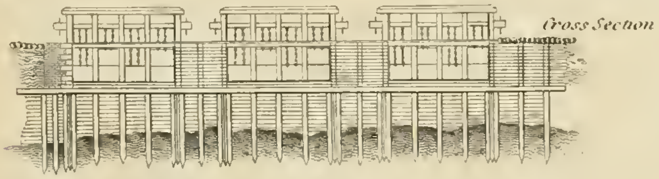
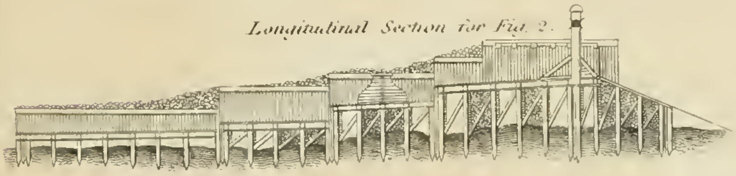


Fig 2.

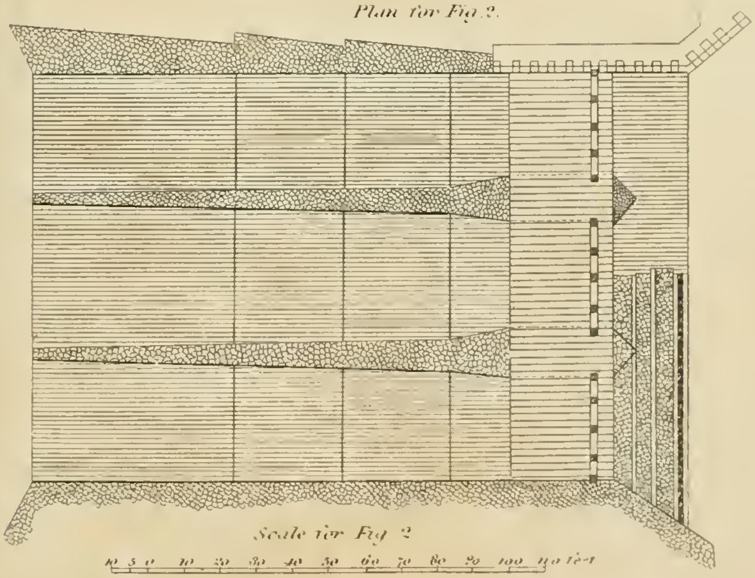
Wooden Wear with Sluices Constructed on the River Wittogra in Russia.



Longitudinal Section for Fig. 2.



Plan for Fig. 2.



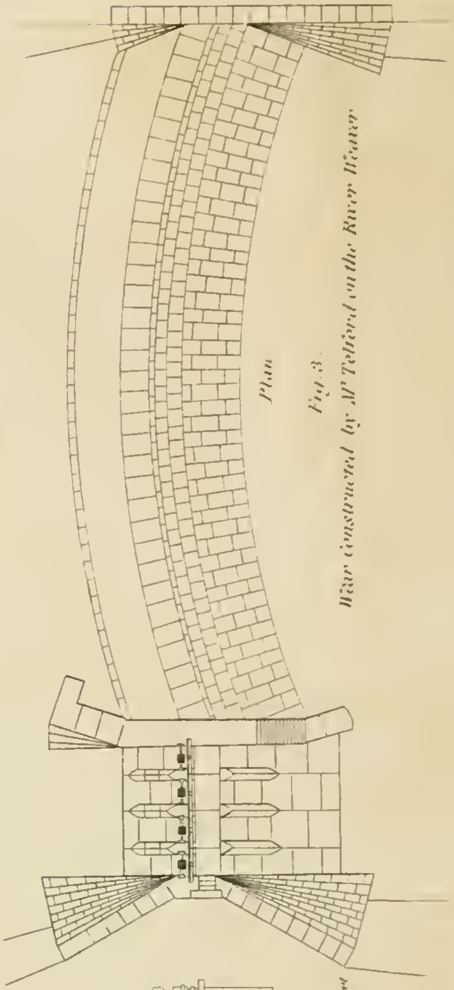
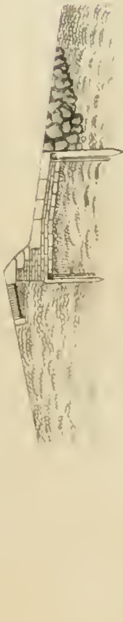
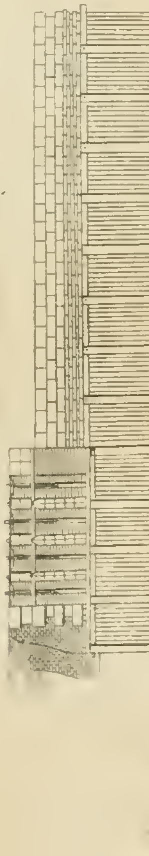


Fig. 3.

Wear Constructed by Mr Telford on the River Weaver



Cross Section for Fig 3



Part of Elevation of Fig. 3

Scale for Fig. 3

NAVIGATION, INLAND. *PLATE CCCCVII.*

Fig 2

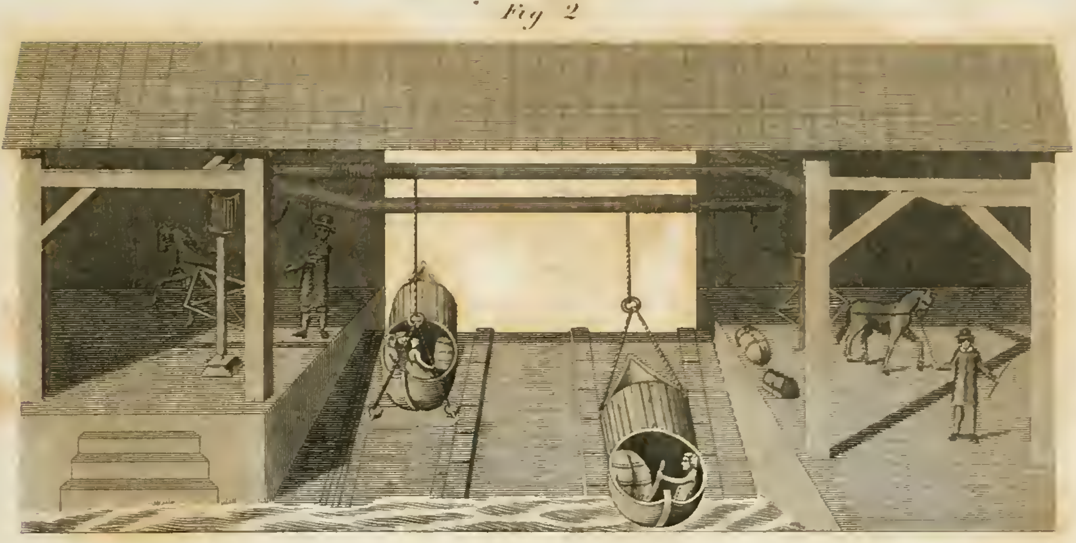


Fig 1

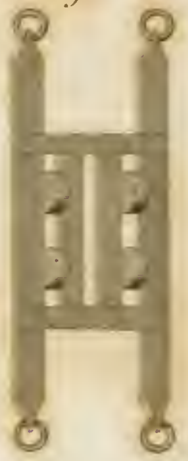


Fig 4

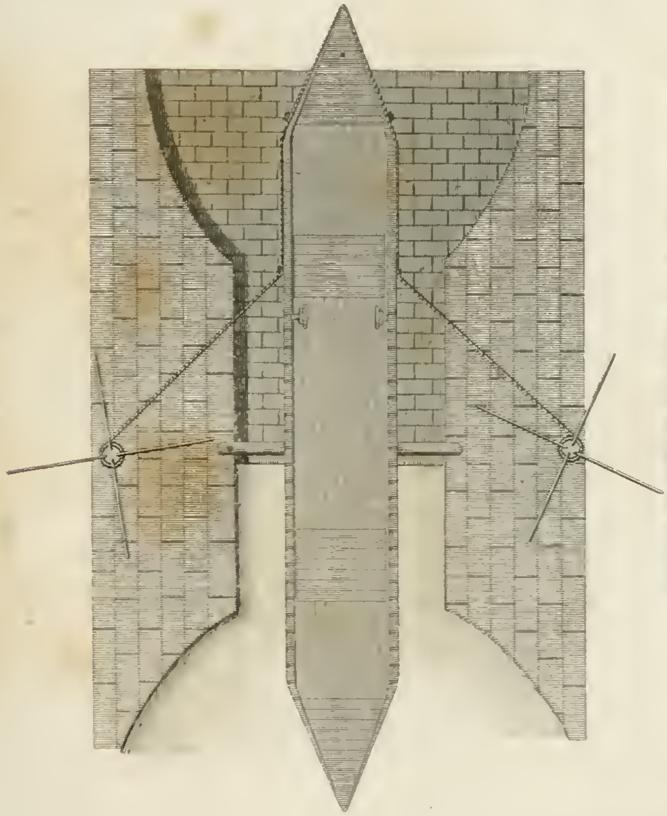


Fig 3

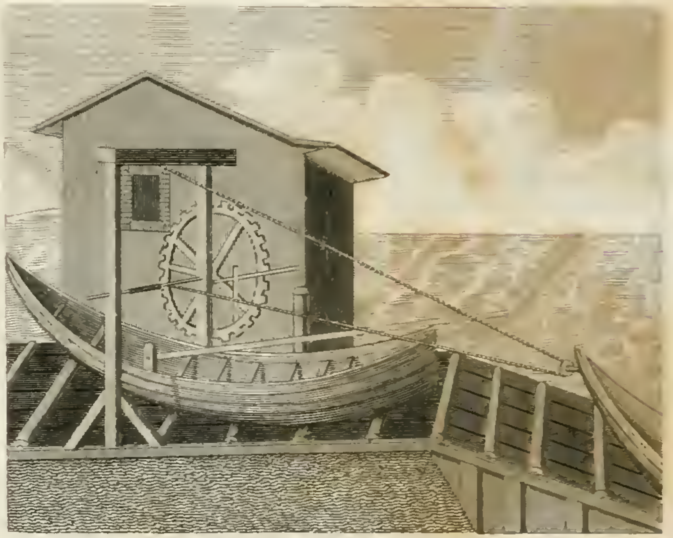
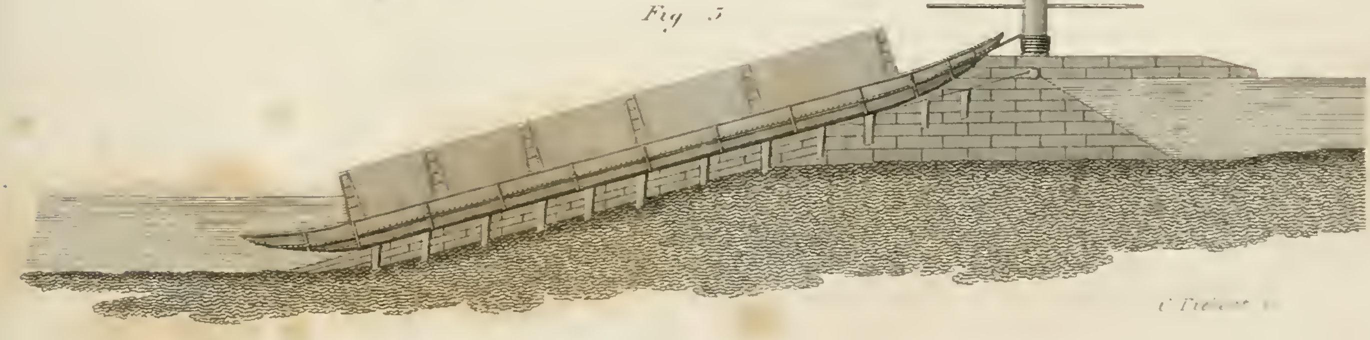


Fig 5



C. Pickett sc.

NAVIGATION, INLAND. *PLATE CCCCVIII.*

CANAL CUTTING

Fig. 1.

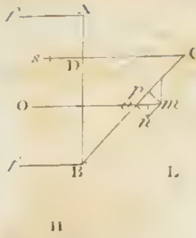


Fig. 2.

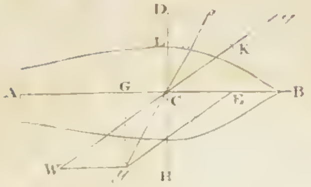


Fig. 4.

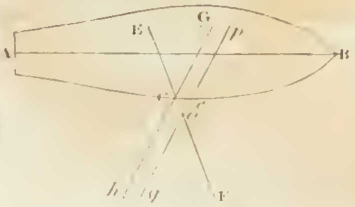


Fig. 3.

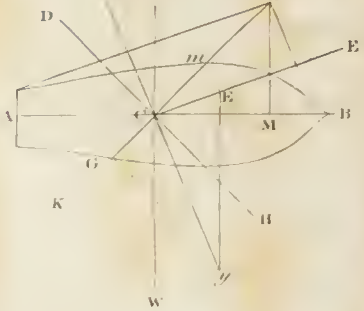


Fig. 5.
Prob. 1. Case 1

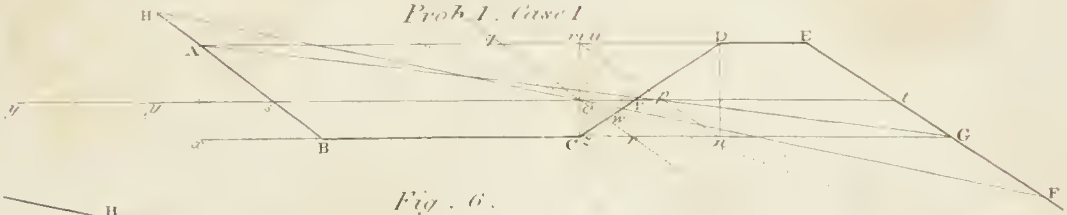


Fig. 12

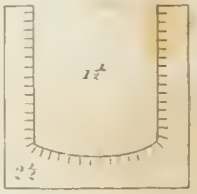


Fig. 6.
Prob. 1. Case 2

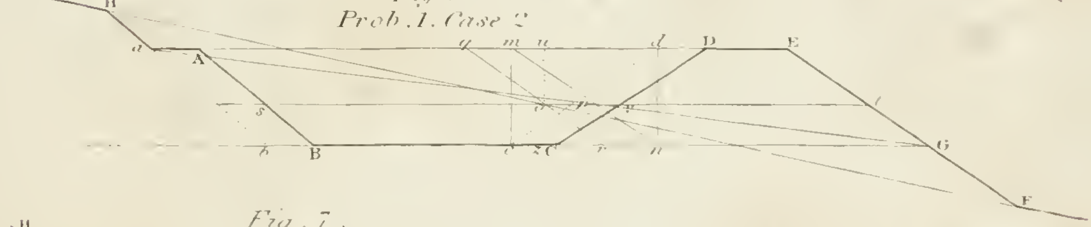


Fig. 13.

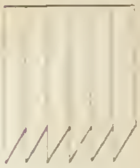


Fig. 7.
Prob. II.

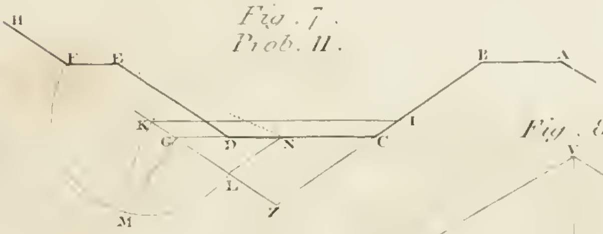


Fig. 15.

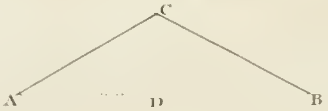


Fig. 8.
Prob. III.

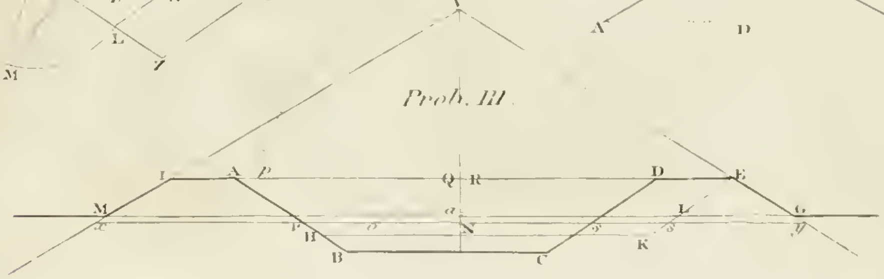


Fig. 14.

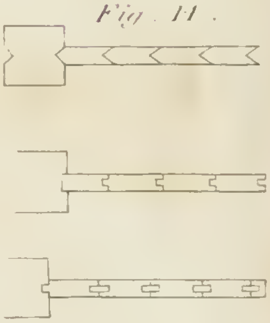


Fig. 9.
Prob. IV.

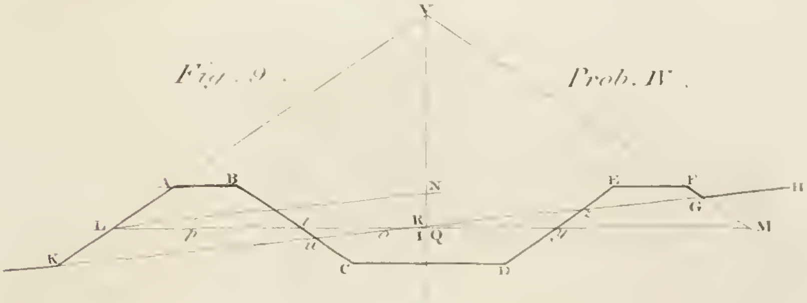


Fig. 11

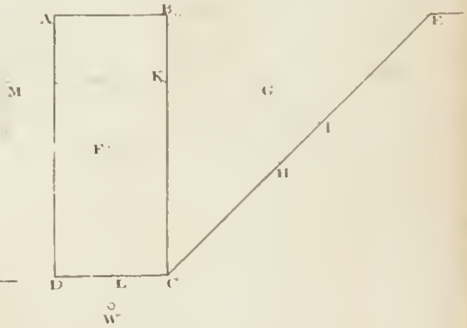
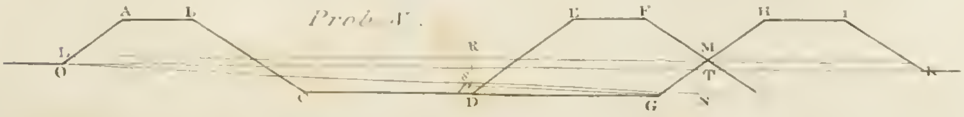


Fig. 10.
Prob. V.



NAVIGATION, INLAND. *PLATE CCCCIX.*

Fig. 1. Single Lock on LANGUEDOC CANAL.

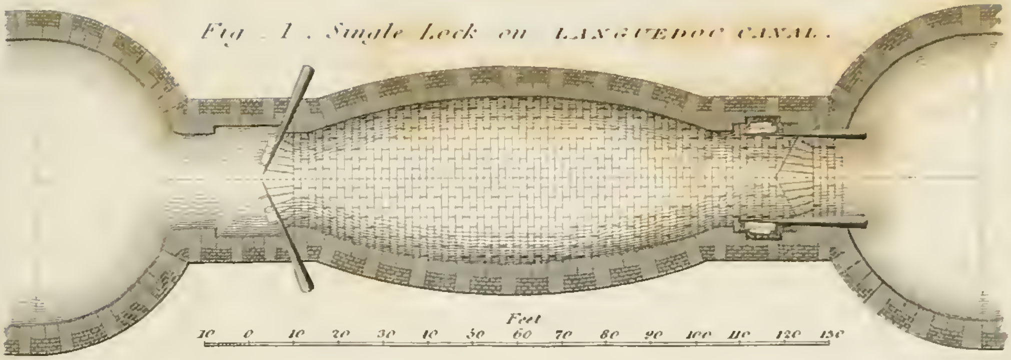


Fig. 2.

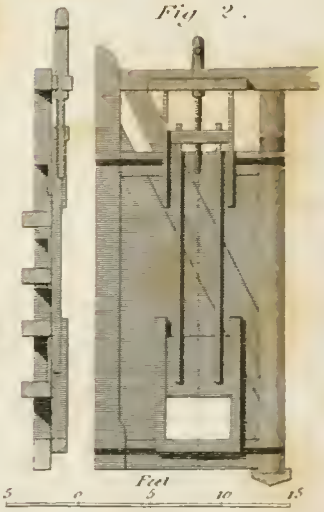


Fig. 7. Circular Lock at Agde.

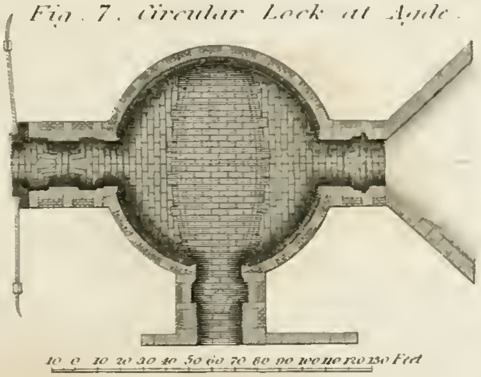


Fig. 3.

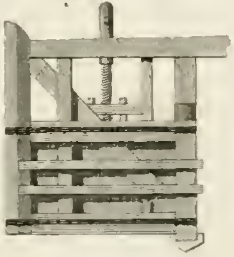


Fig. 4.

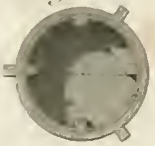


Fig. 5.

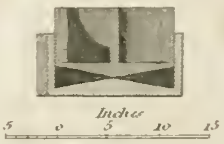


Fig. 6.

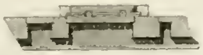


Fig. 8.
Section. CANAL OF BURGUNDY.

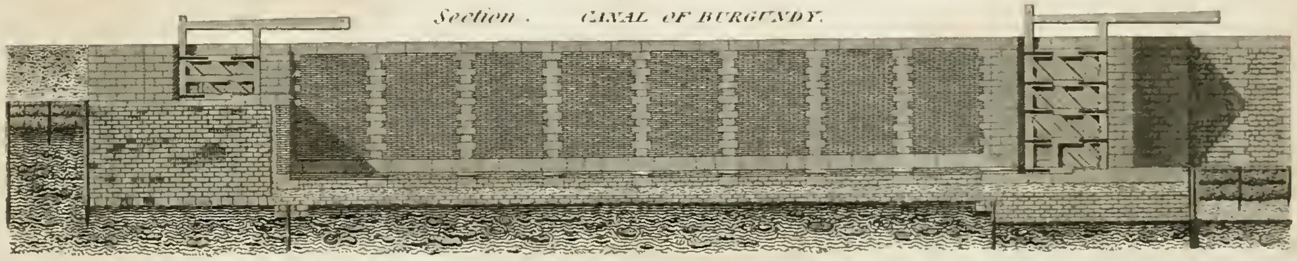
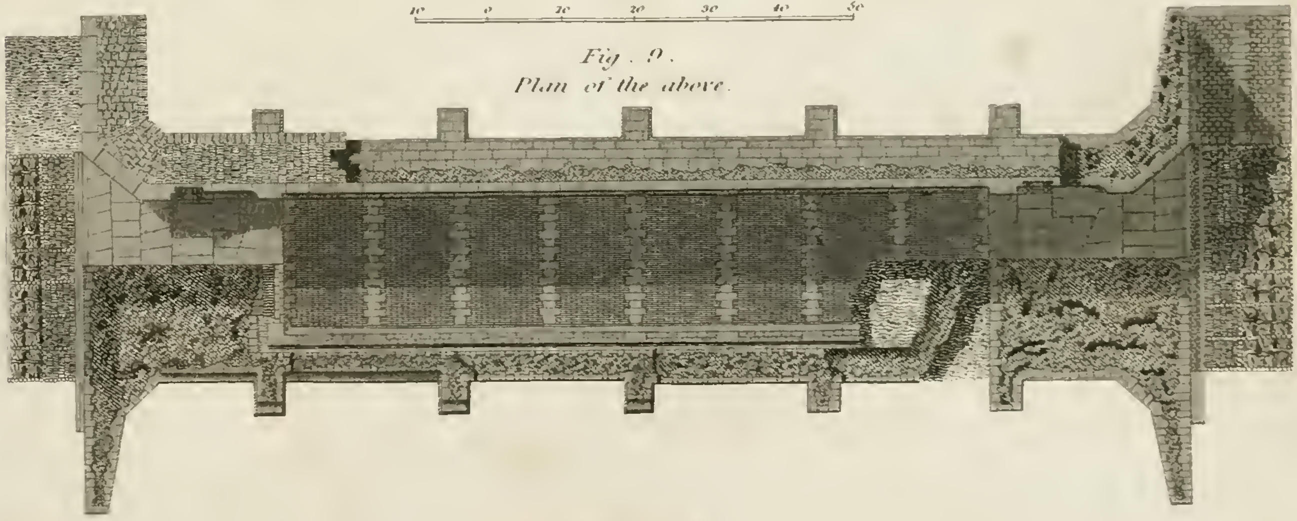


Fig. 9.
Plan of the above.



H. Andersen S.

Fig. 1. CALEDONIAN CANAL.

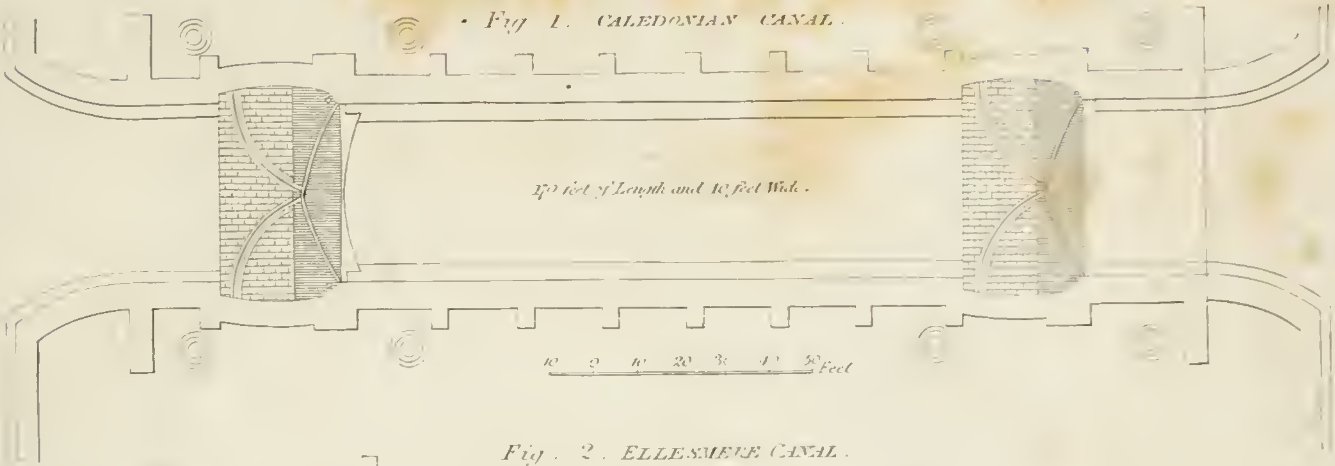


Fig. 2. ELLESMERE CANAL.

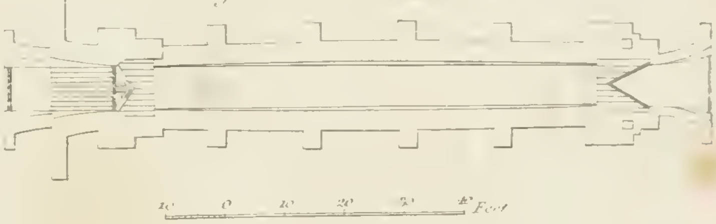


Fig. 3.

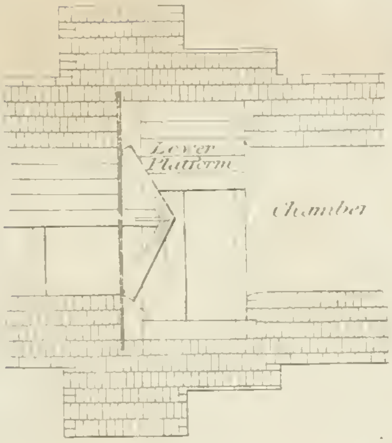


Fig. 4. Section.

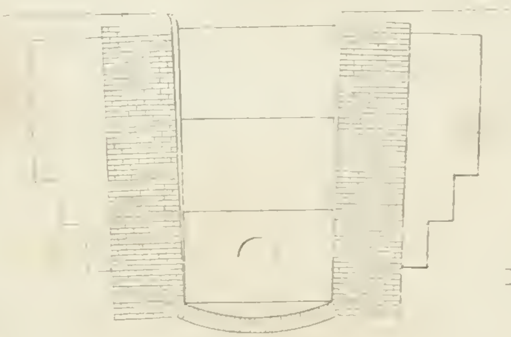


Fig. 5.

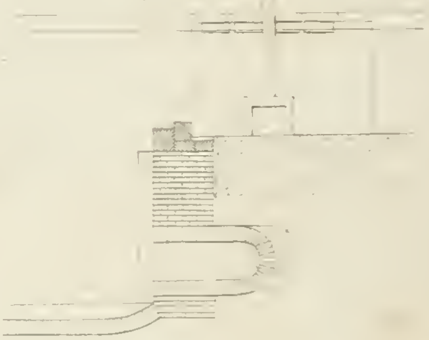


Fig. 6.

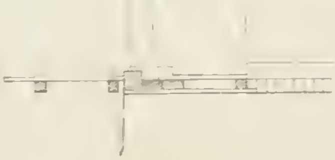


Fig. 7. Forebay.

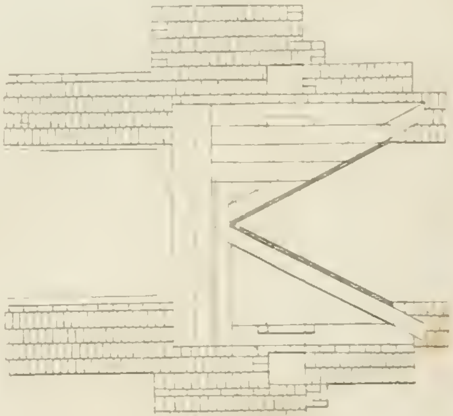


Fig. 8. Lower Gate.

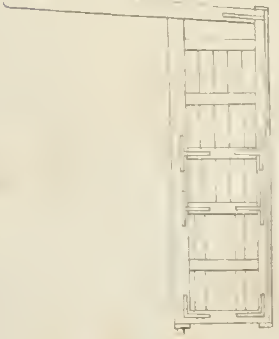
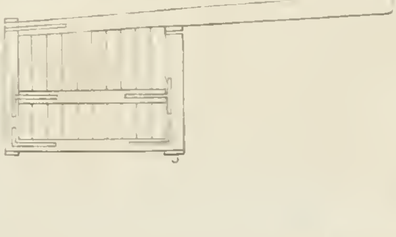


Fig. 9. Upper Gate.



10 5 0 10 Feet

NAVIGATION, INLAND.

PLATE CCCCXV.

Fig 1 RUSSIAN LOCK

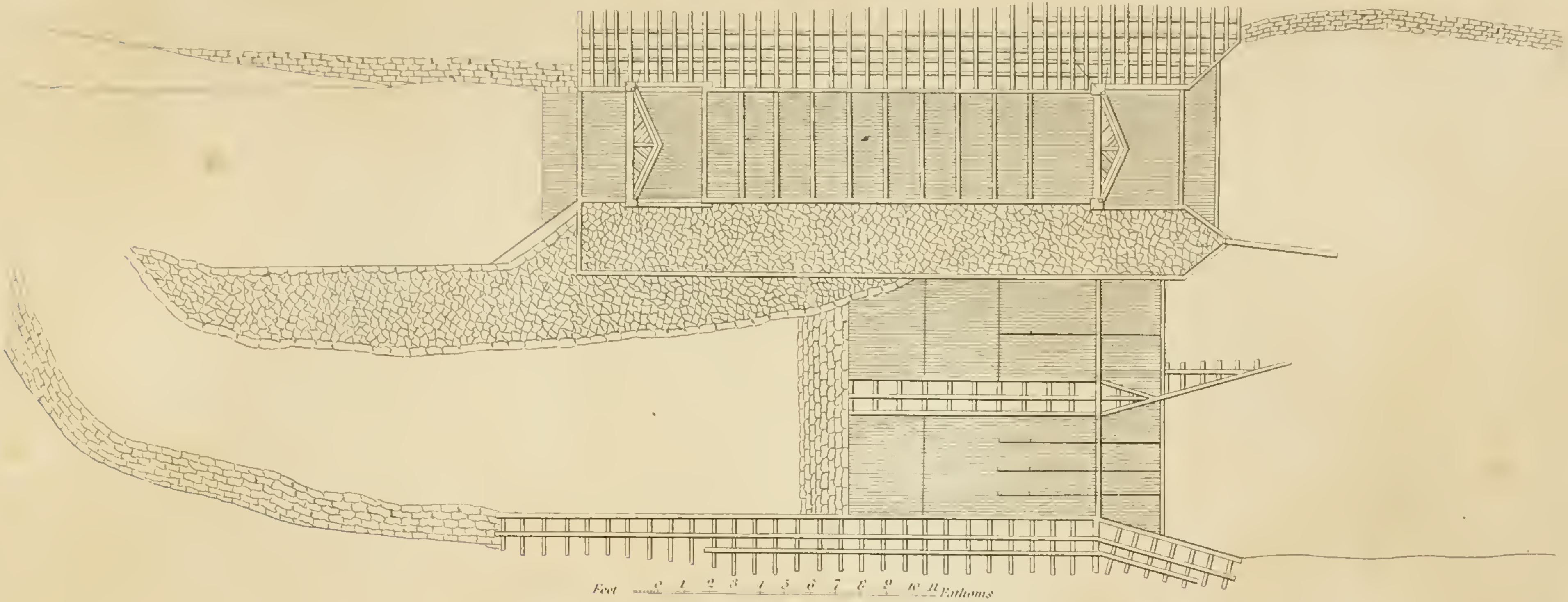


Fig 2.

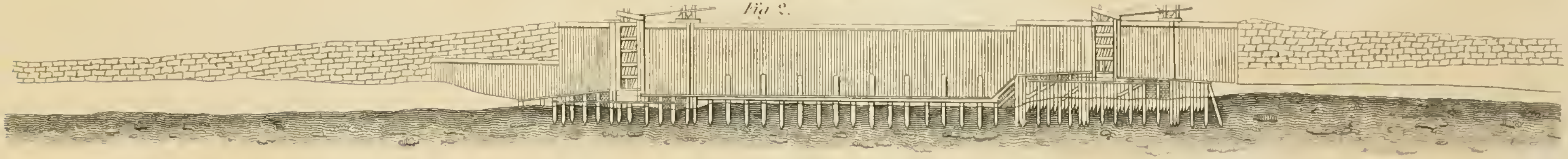


Fig 3.

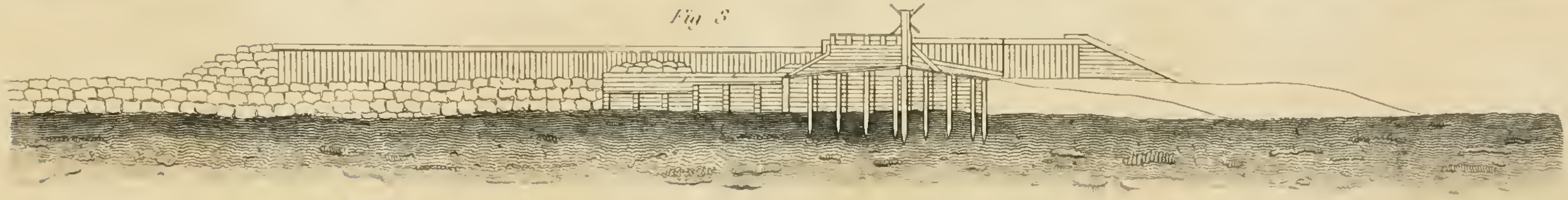
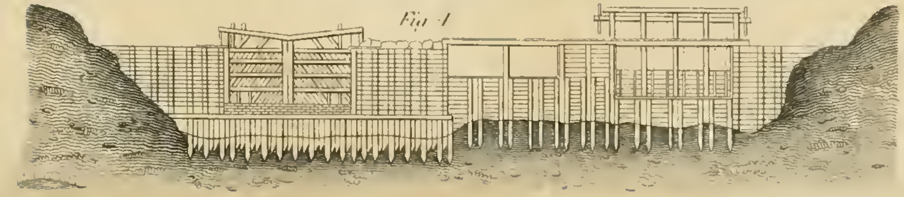
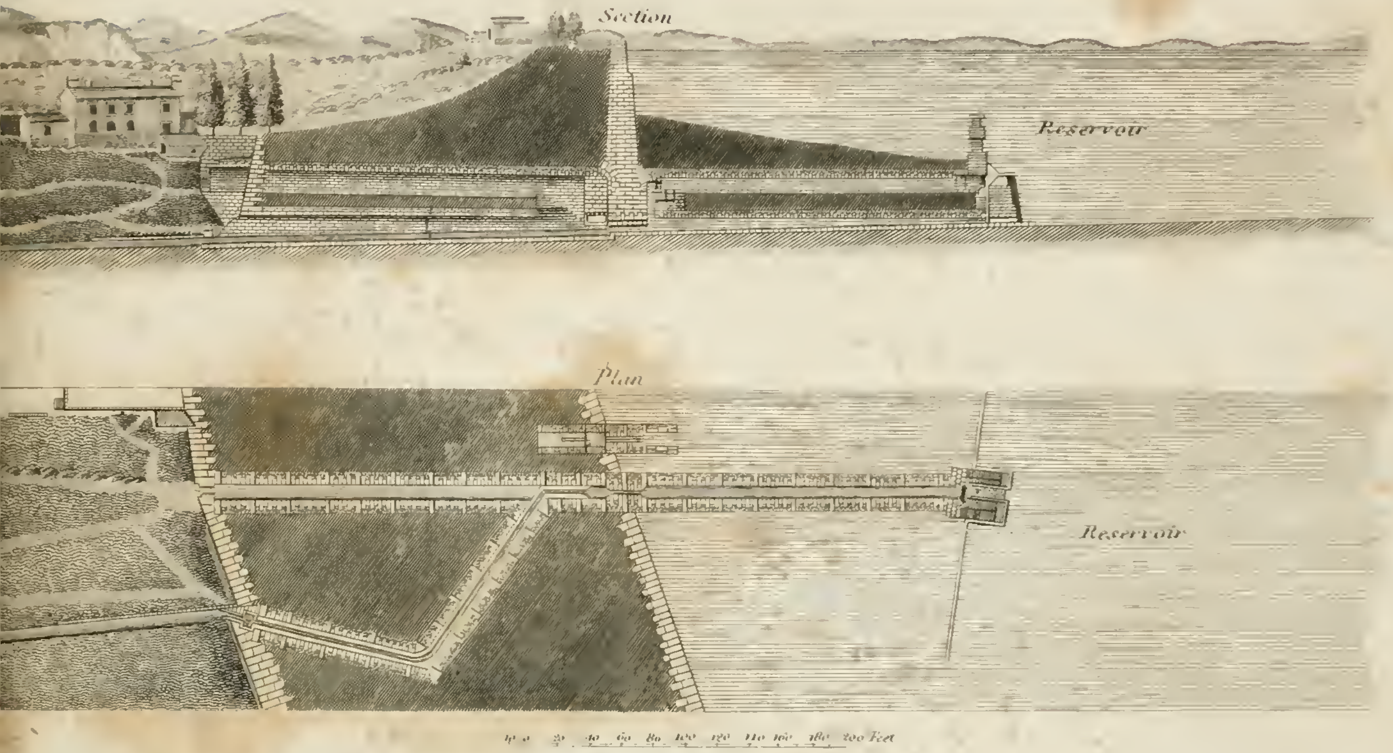


Fig 4.

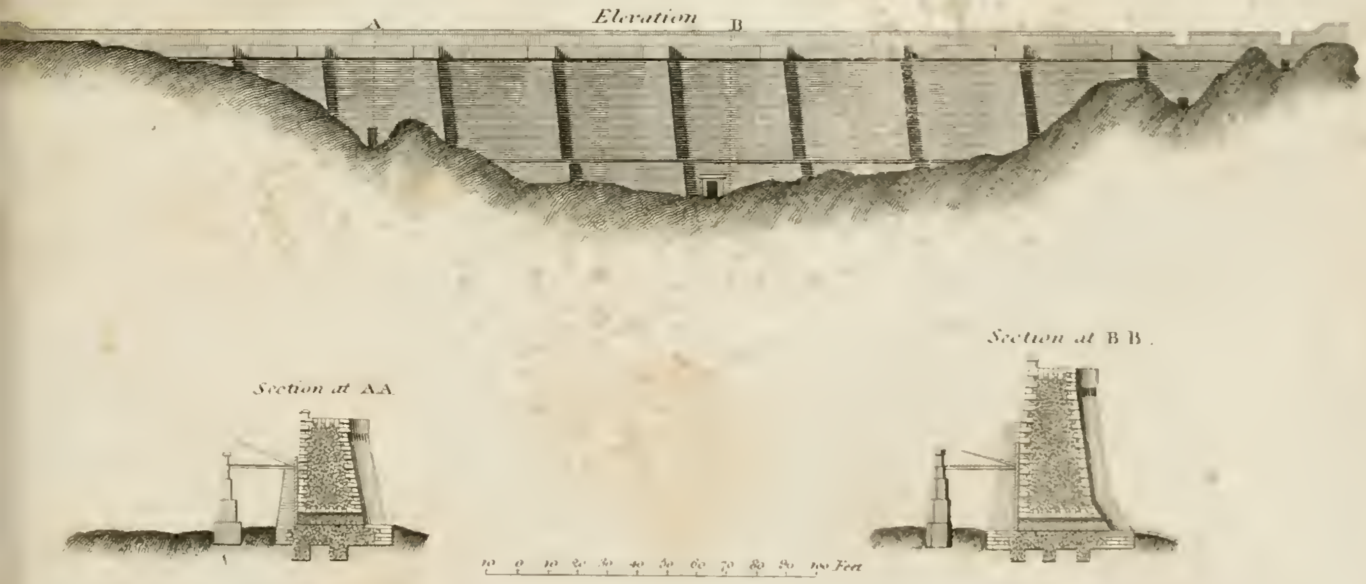


NAVIGATION INLAND. *PLATE CCCCXII.*

Plan and Section of the RESERVOIR *of* ST. FERRIOL *on the* LANGUEDOC CANAL.

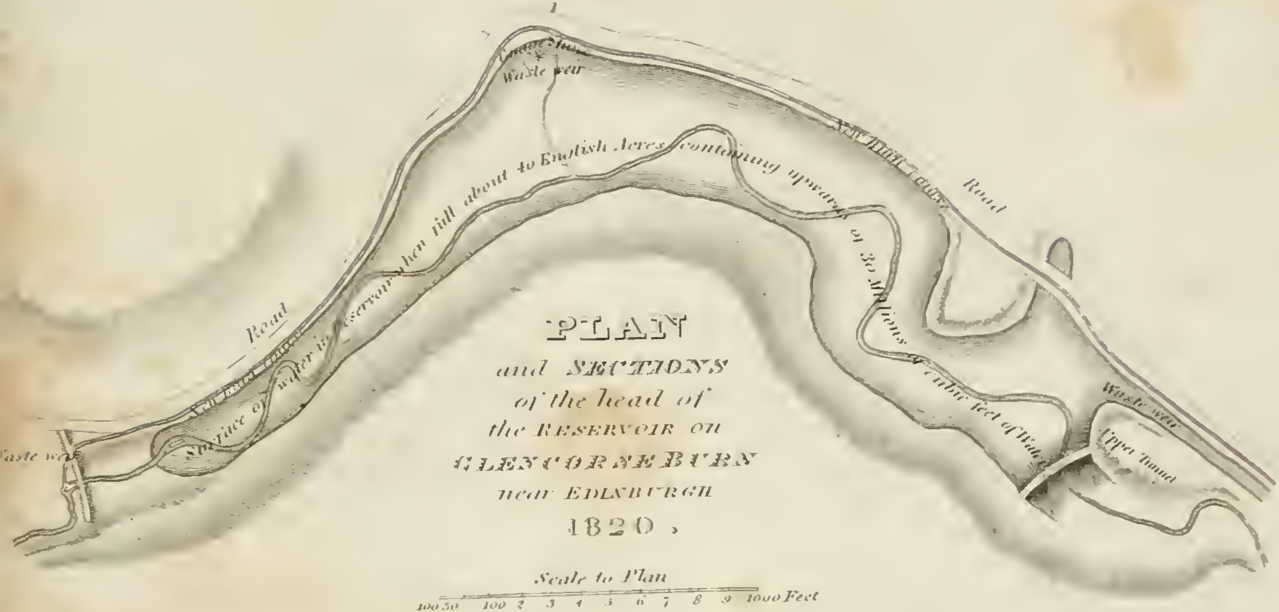


Elevation and Section of the EMBANKMENT *of the* LAMPY RESERVOIR *on the* LANGUEDOC CANAL.



NAVIGATION INLAND. PLATE CCCCXIII.

Fig. 1.


1
Mill Stank
Waste weir
Surface of water in Reservoir when full about 40 English Acres containing upwards of 30 Millions of cubic feet of Water
New Mill Lade
Road
Road
New Mill Lade
Waste weir
Waste weir
Upper Tunnel
Scale to Plan
100 50 100 2 3 4 5 6 7 8 9 1000 Feet

PLAN
and SECTIONS
of the head of
the RESERVOIR on
GLENCORSE BURN
near EDINBURGH
1820.

Fig. 2.

Section across the VALLEY *of* GLENCORSE BURN *or* LONGITUDINAL SECTION *of the* HEAD

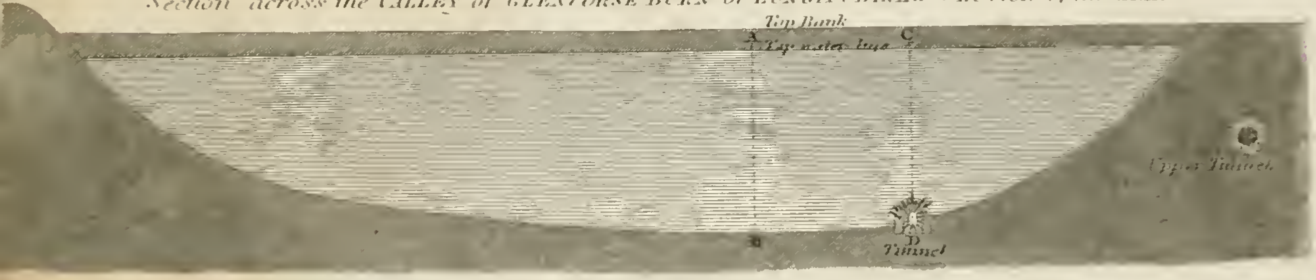


Fig. 3.

Cross Section of the HEAD *in the* LINE AB *of the* LONGITUDINAL SECTION

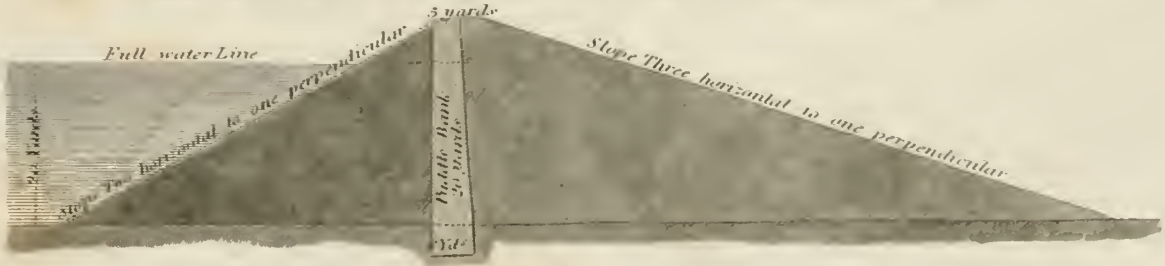
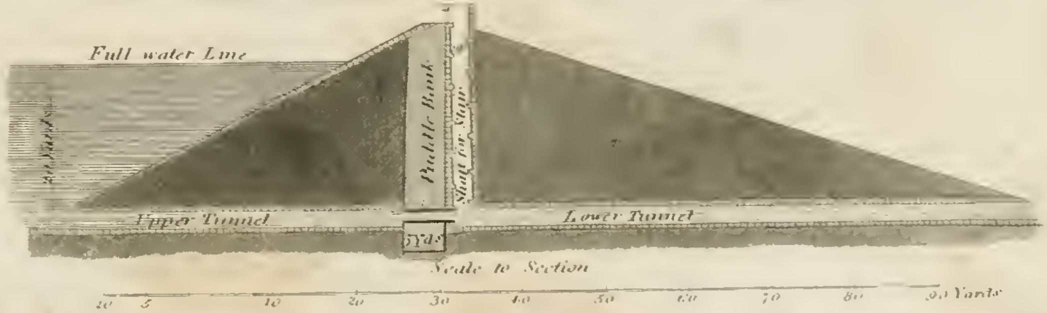

5 yards
Full water Line
Slope Two horizontal to one perpendicular
Slope Three horizontal to one perpendicular
Puddle Bank 20 Yards
Yds

Fig. 4.

Cross Section of the HEAD *in the* LINE CD *of the* LONGITUDINAL SECTION



NAVIGATION INLAND. PLATE CCCCXIV.

Fig. 1. AQUEDUCT DE CESSE LANGUEDOC CANAL.

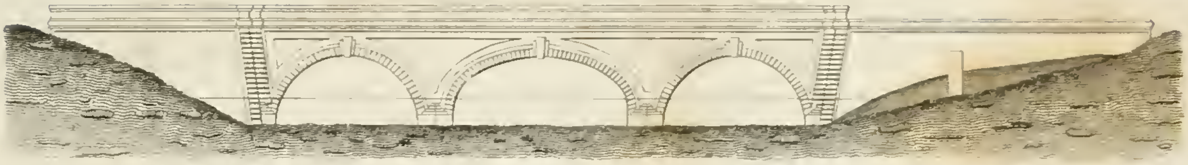
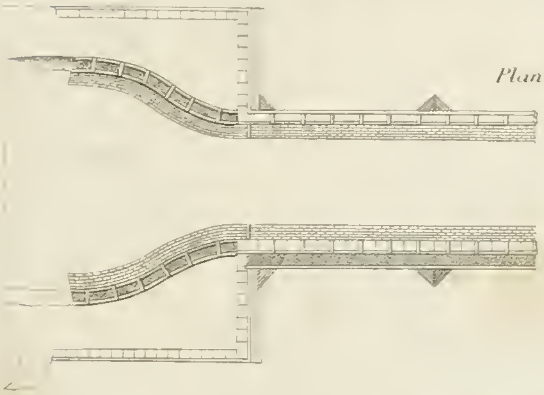


Fig 2
Plan and Section of the above



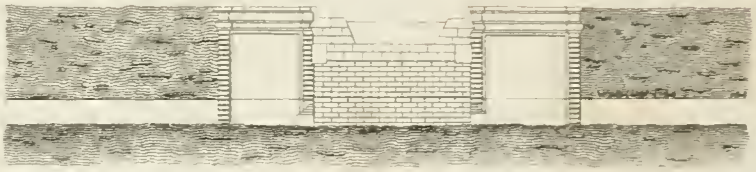


Fig. 3.
KELVIN AQUEDUCT ON THE FORTH AND CLYDE CANAL.

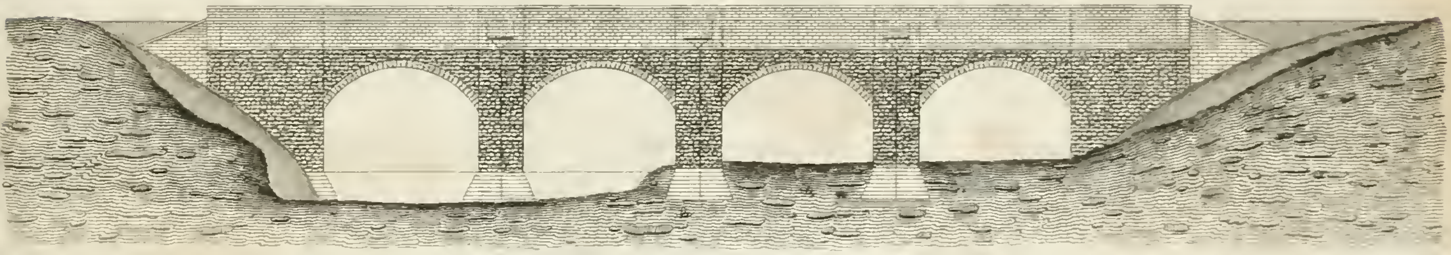


Fig. 4. Plan and Section of the above

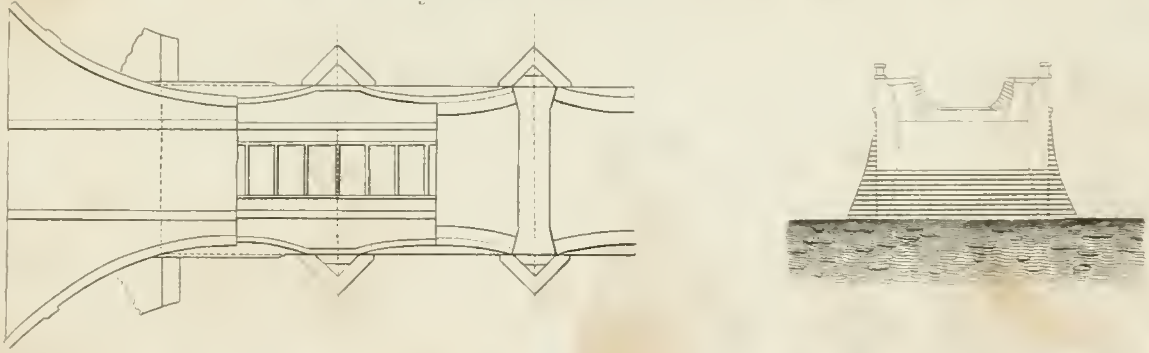
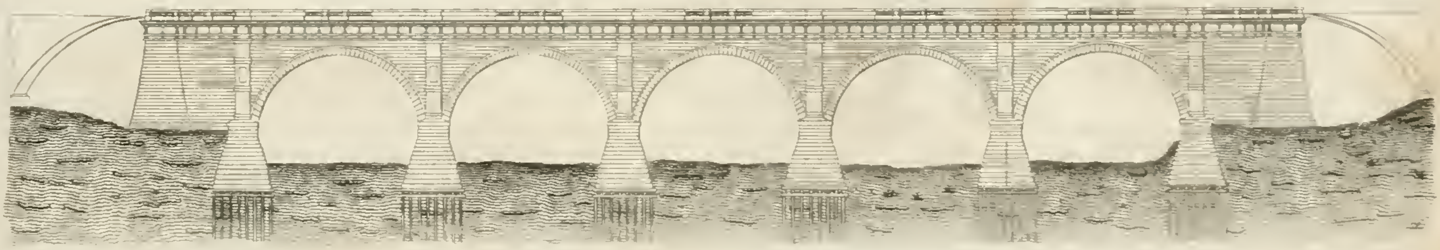


Fig. 5. LUNE AQUEDUCT LANCASTER CANAL.



Scale to the plans & Sections

NAVIGATION, INLAND.

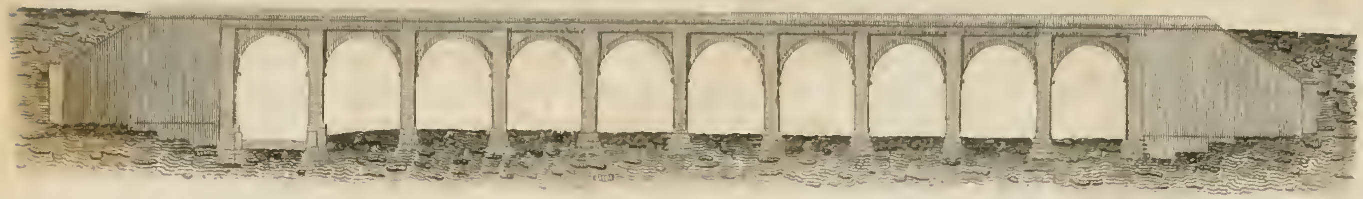


Fig. 1 CHIRK AQUEDUCT

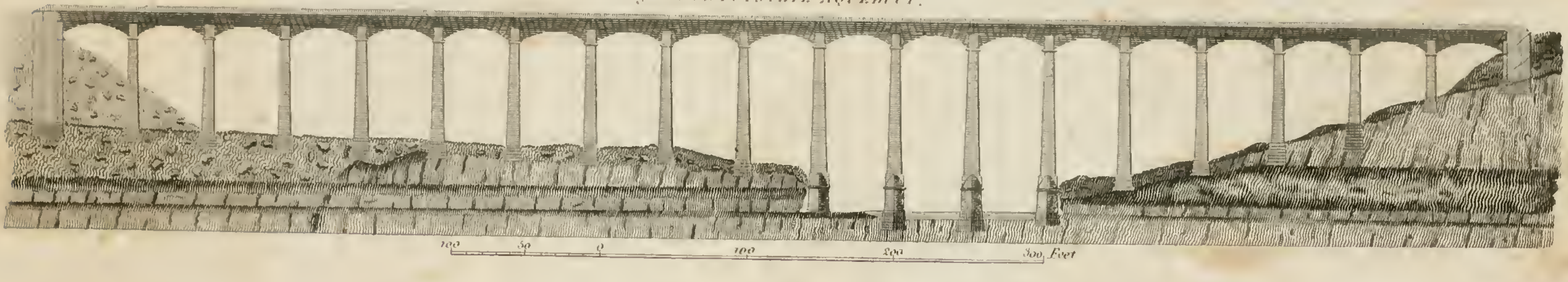


Fig. 2. PONTCYSYLTE AQUEDUCT.

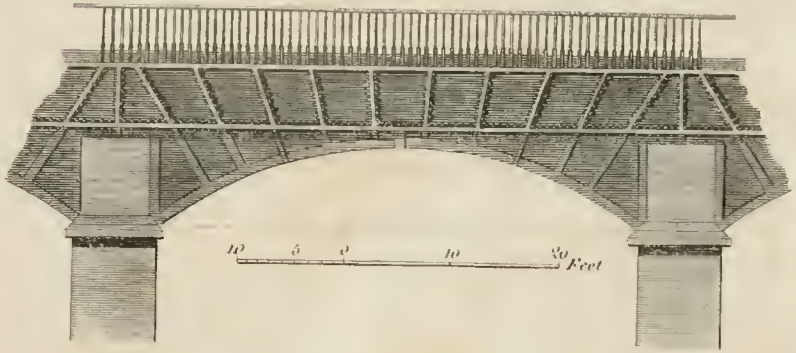


Fig. 3. ONE ARCH PONTCYSYLTE.

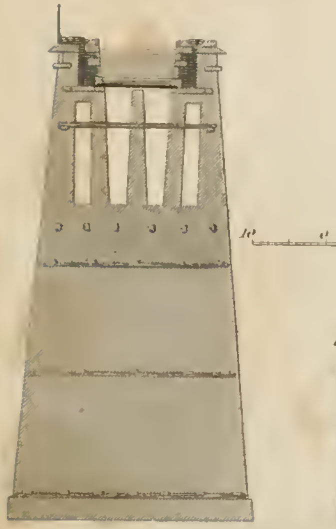


Fig. 8. Section. CHIRK.

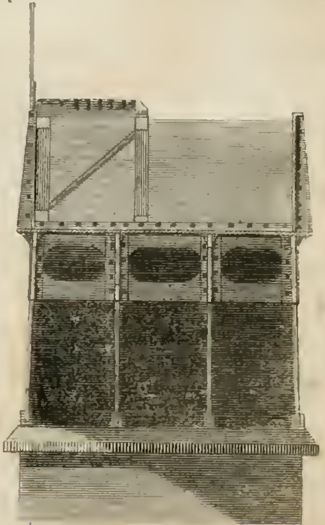


Fig. 4. Section PONTCYSYLTE

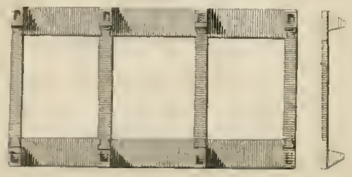


Fig. 5 Ties on Pier at Springing

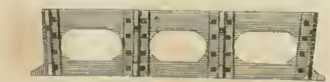


Fig. 6. Cross tye Plate

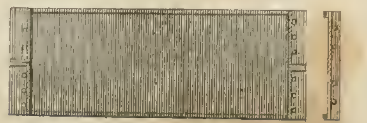


Fig. 7. Bottom Plate

NAVIGATION INLAND. *PLATE CCCCXVI.*

Fig 1

Draw Bridge

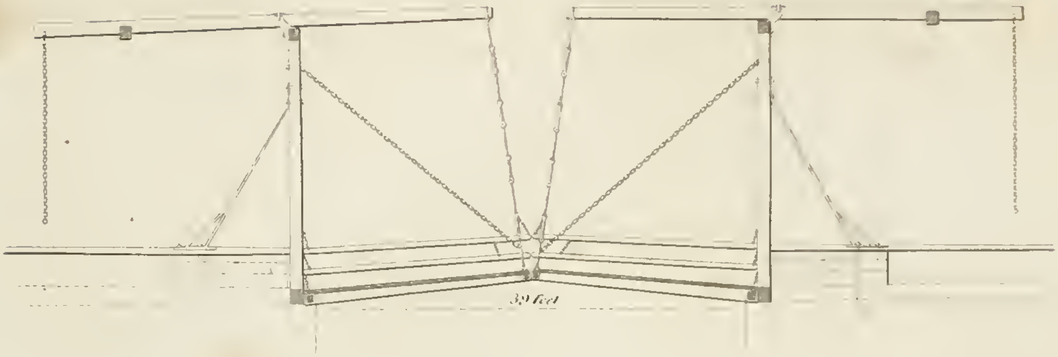


Fig. 2

Timber Turn Bridge on the Grand Surry Canal

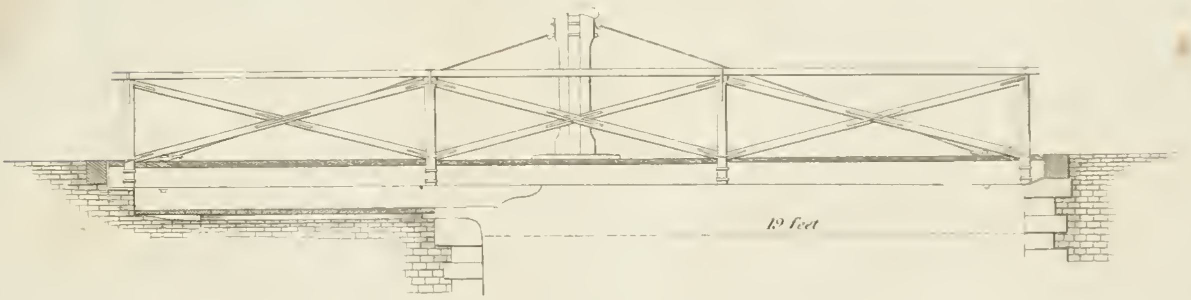
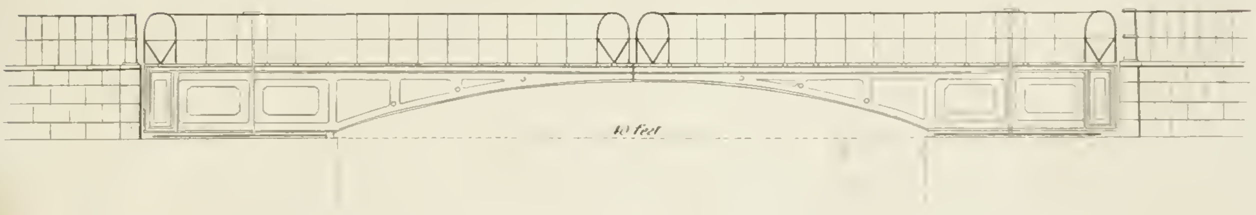
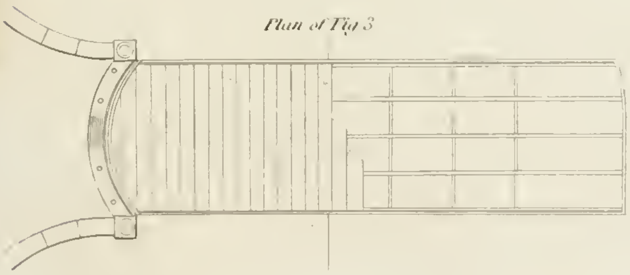


Fig 3

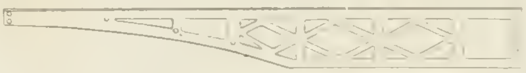
Turn Bridge of Cast Iron on the Caledonian Canal



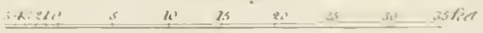
Plan of Fig 3



Centre Rib of Fig 3



Scale for Fig 1



Scale for Fig 3

Scale for Fig 2

NAVIGATION, INLAND. *PLATE CCCCXVIII.*

SKEWED BRIDGES.

Fig. 1

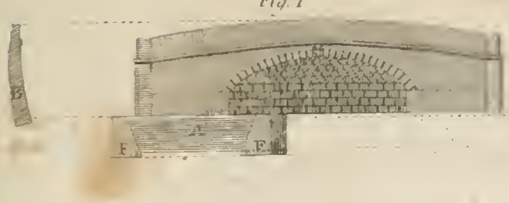


Fig. 2.

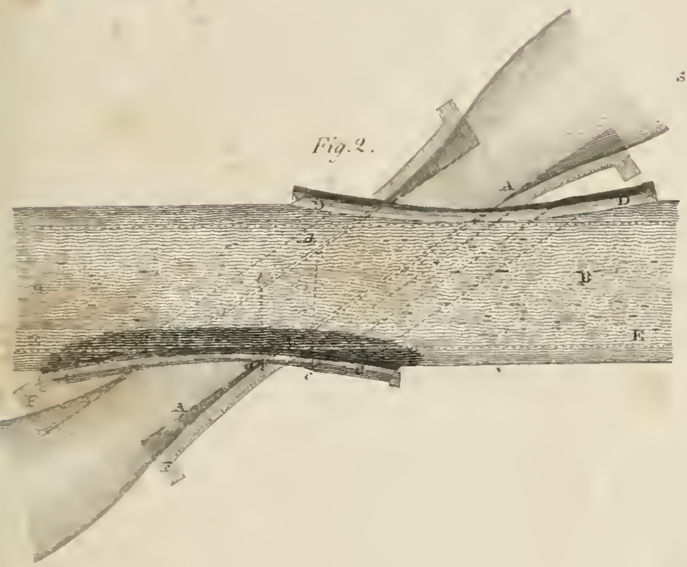


Fig. 3.

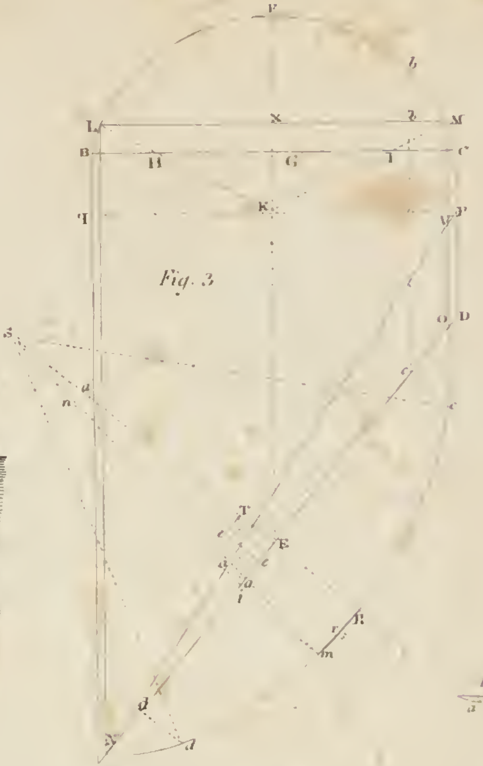


Fig. 4

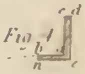


Fig. 5

Fig. 6.

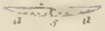


Fig. 8. *Fig. 9* *Fig. 10* *Fig. 11* *Fig. 12* *Fig. 13.*

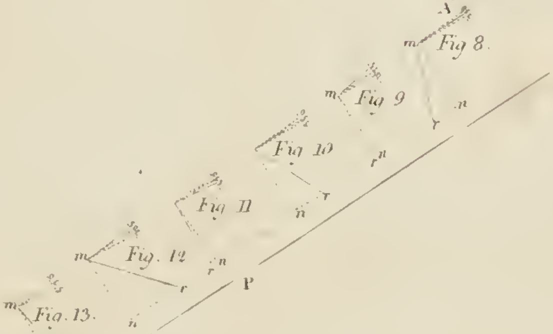
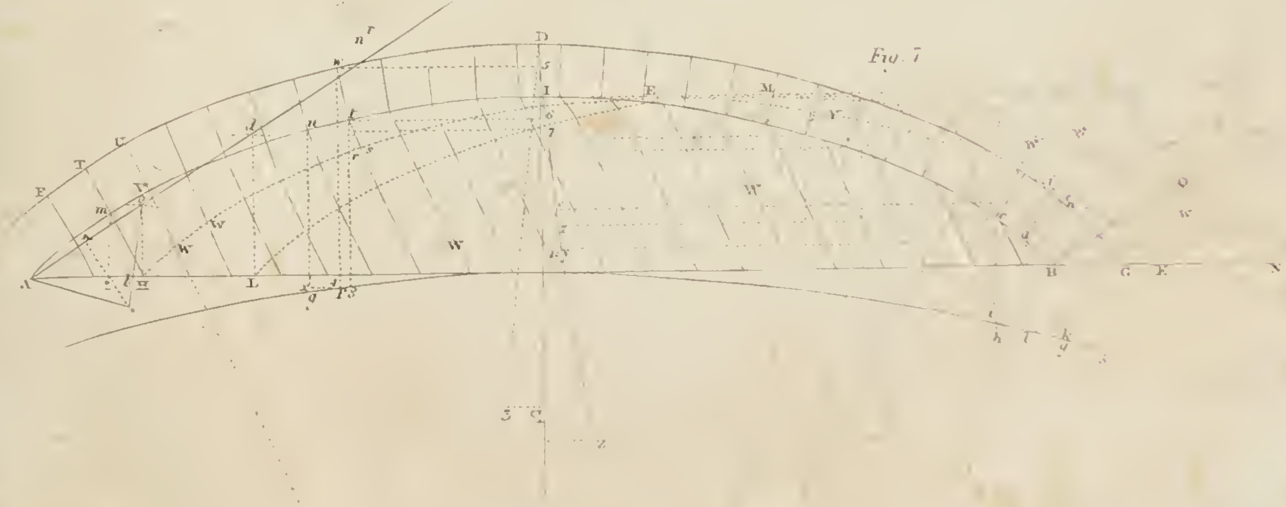


Fig. 7



M.A. Nicholson. del.

NAVIGATION, INLAND. PLATE CCCCXIX.

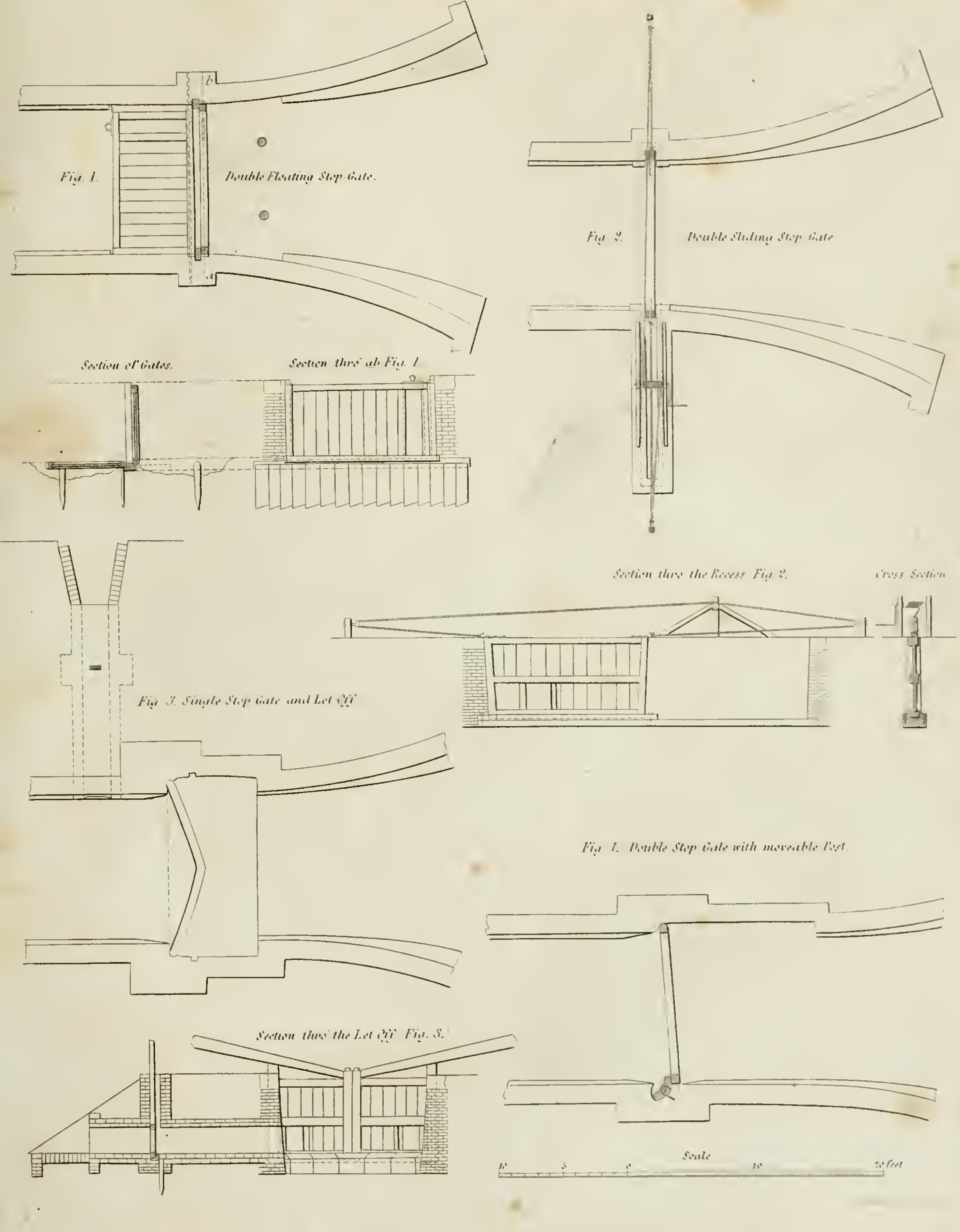
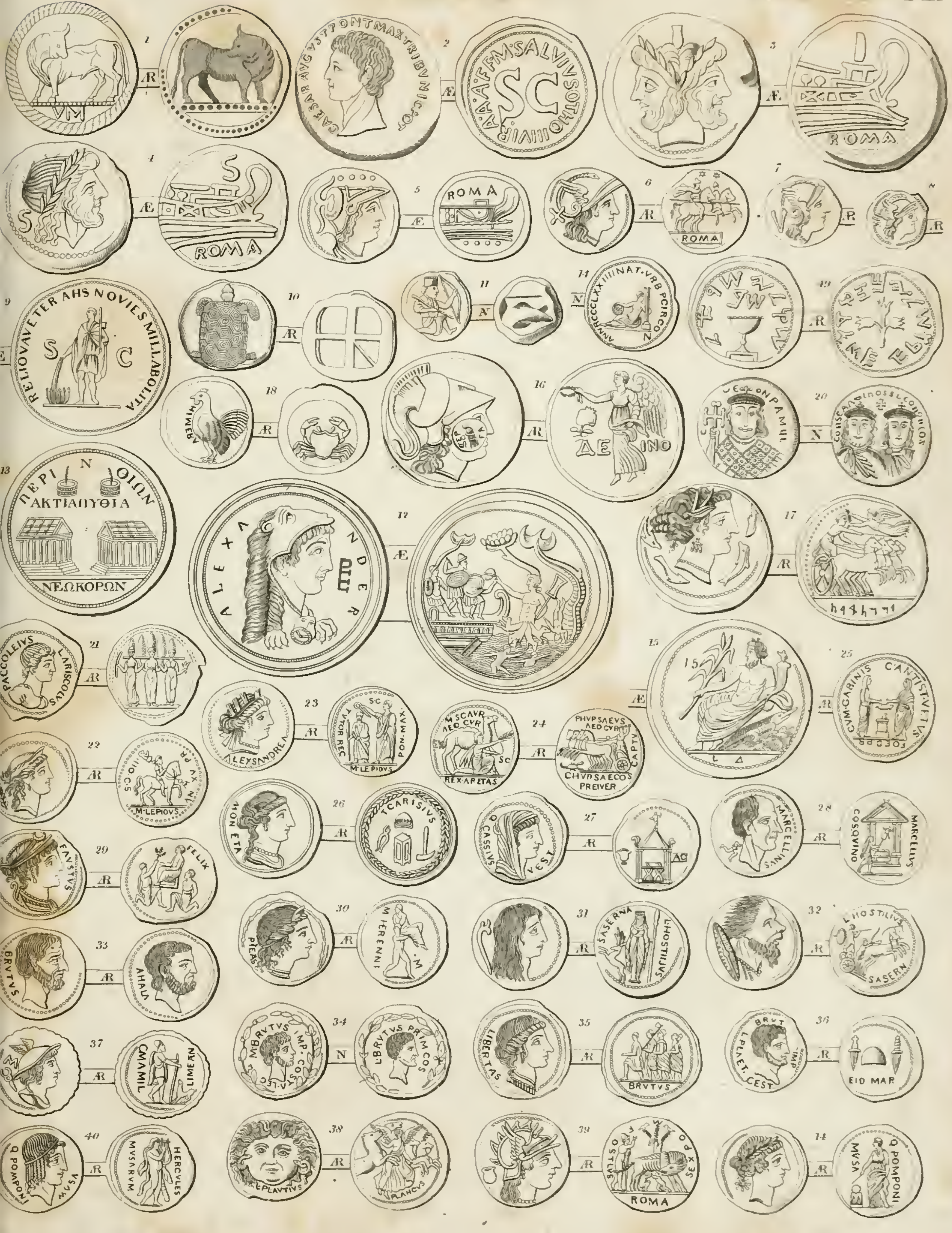


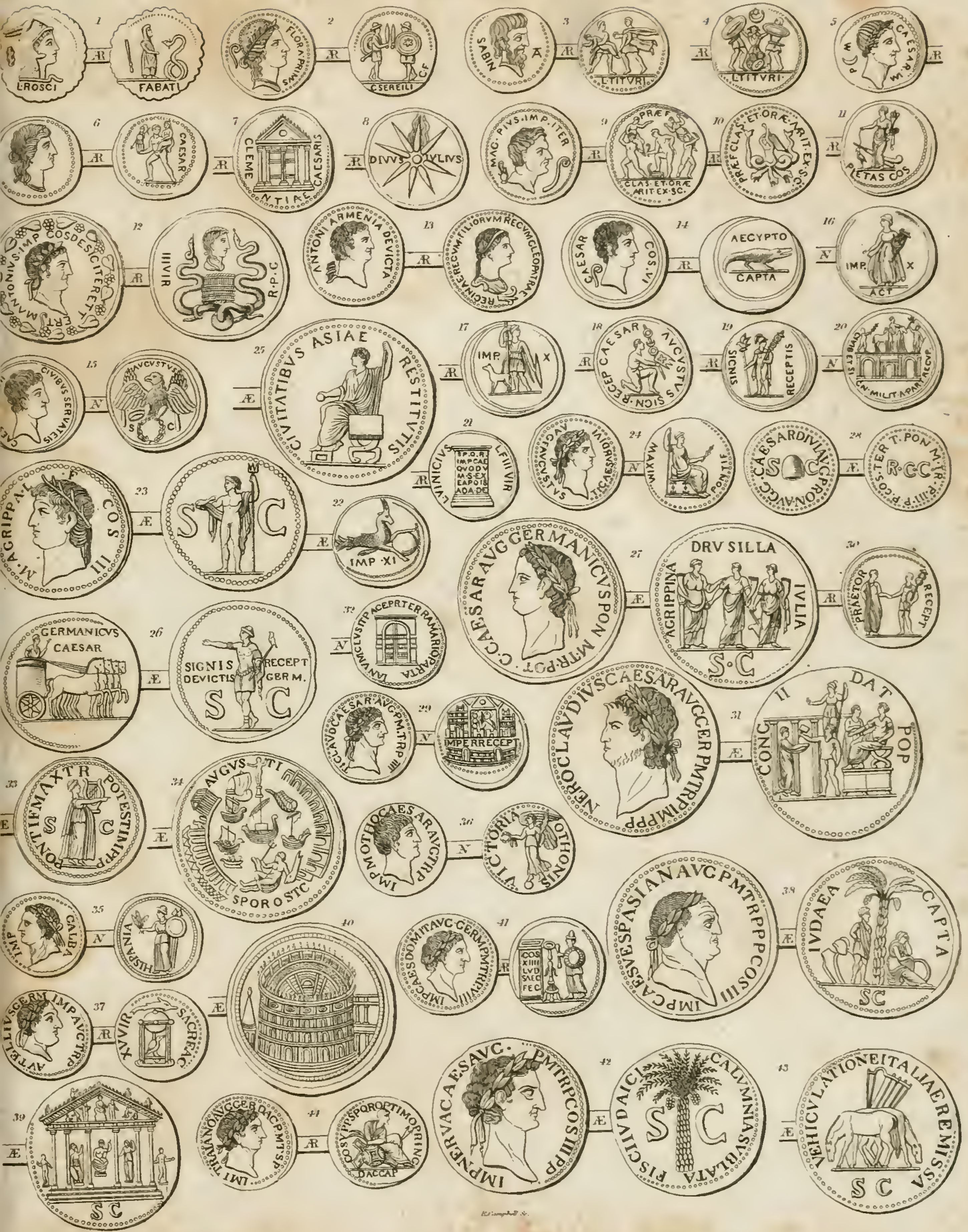
Fig. 1.
Double Floating Stop-Gate.
b
a
Section of Gates.
Section thro' ab Fig. 1
Fig. 2.
Double Sliding Stop Gate
Section thro' the Recess Fig. 2.
Cross Section
Fig. 3. Single Stop Gate and Let Off
Fig. 4. Double Stop Gate with moveable Post.
Section thro' the Let Off Fig. 3.
Scale
10
5
0
10
20 feet

NUMISMATOLOGY

PLATE CCCCXX



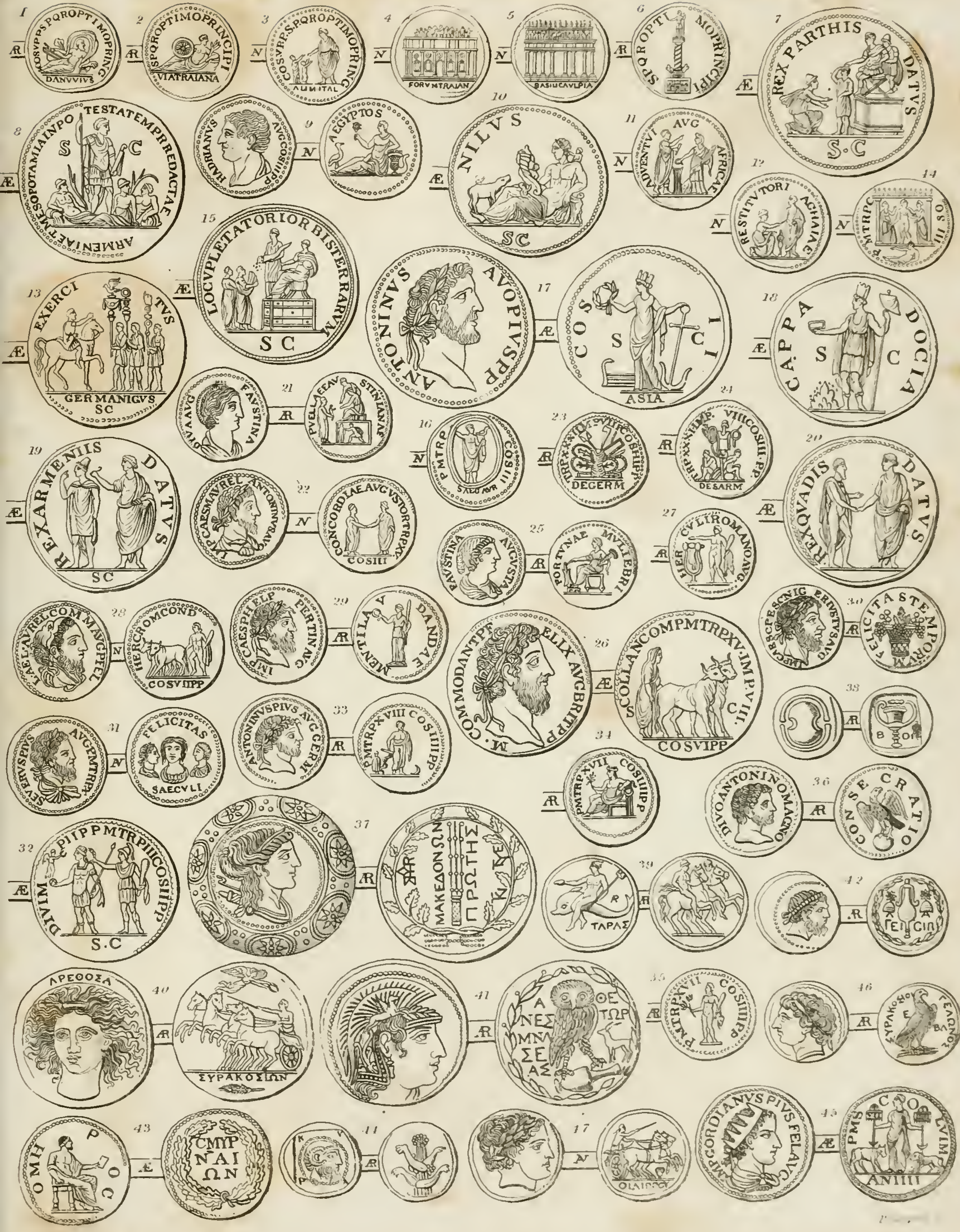
NUMISMATOLOGY. *PLATE CCCCXXI*


1 L·ROSCI Æ FABATI
2 FLORA PRIMUS Æ C.SERE(I)LI CF
3 SABIN A Æ L·TITVRI
4 Æ L·TITVRI
5 M CAESAR·M Æ
6 Æ CAESAR
7 Æ CLEMENTIAE CAESARIS
8 Æ DIVVS IVLIVS
9 MAG·PIVS·IMP·ITER Æ PRAEF CLAS·ET·ORAE ARIT·EX·SC.
10 PRAEF CLAS·ET·ORAE·ARIT·EX·S.C.
11 Æ PIETAS COS
12 M·ANTONIVS·IMP·COS·DESIG·ITER·ET·TERT Æ IIIVIR R·P·C
13 ANTONI ARMENIA DEVICTA Æ REGINAE·REGVM·FILIORVM·REGVM·CLEOPATRAE
14 CAESAR COS·VI Æ AEGYPTO CAPTA
16 N IMP X ACT
15 CIVIBVS SERVATEIS N AVGVSTVS S C
25 Æ CIVITATIBVS ASIAE RESTITVTIS
17 Æ IMP X
18 Æ CAESAR AVGVSTVS SIGN·RECEP
19 Æ SIGNIS RECEPTIS
20 N CAESARI AVGV(ST) S P Q R CN·MILIT·A PART·RECVP
21 Æ L·VINICIVS L·F·III·VIR S·P·Q·R IMP·CAE QVOD V M·S·EX EA P·Q·IS AD A DE
24 SALVS GENERIS HVMANI T·CAESAR DIVI N MAXIM PONTIF
28 CAESAR DIVI AVG PRON·AVG S C Æ T·PON M TR P III P P COS TER R·C·C
23 M·AGRIPPA L F COS III Æ S C
22 Æ IMP·XI
27 C·CAESAR AVG GERMANICVS PON M TR POT Æ DRVSILLA AGRIPPINA IVLIA S·C
30 Æ PRAETOR RECEPT
26 GERMANICVS CAESAR Æ SIGNIS RECEPT DEVICTIS GERM. S C
32 N IANVM CLVSIT PACE P R TERRA MARIQ PARTA
29 TI CLAVD CAESAR AVG P M TR P III N IMPER RECEPT
31 NERO CLAVDIVS CAESAR AVG GER P M TR P IMP P P Æ CONG II DAT POP
33 PONTIF MAX TR POTEST IMP P S C
34 Æ AVGVSTI SPOR OST C
36 IMP M OTHO CAESAR AVG TR P N VICTORIA OTHONIS
35 IMP GALBA N HISPANIA
38 IMP CAES VESPASIAN AVG P M TR P P P COS III Æ IVDAEA CAPTA SC
37 A VITELLIVS GERM IMP AVG TR P Æ XV VIR SACR FAC
40 Æ
41 IMP CAES DOMIT AVG GERM P M TR P VIII Æ COS XIIII LVD SAEC FEC
39 Æ SC
44 IMP TRAIANO AVG GER DAC P M TR P Æ COS V P P S P Q R OPTIMO PRINC DAC CAP
42 IMP NERVA CAES AVG P M TR P COS III P P Æ FISCI IVDAICI CALVMNIA SVBLATA S C
43 Æ VEHICVLATIONE ITALIAE REMISSA S C

R. Campbell sc.

NUMISMATOLOGY.

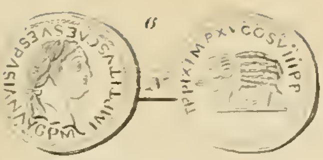
PLATE CCCCXXII



1 Æ COSVPPSPQROPTIMOPRINC DANVVIVS
2 Æ SPQROPTIMOPRINCIPI VIATRAIANA
3 N COSVPPSPQROPTIMOPRINC ALIMITAL
4 N FORVMTRAIAN
5 N BASILICAVLPIA
6 Æ SPQROPTIMOPRINCIPI
7 Æ REX PARTHIS DATVS S·C
8 Æ ARMENIAETMESOPOTAMIAINPOTESTATEMPRREDACTAE S C
9 N HADRIANVS AVGCOSIIIPP AEGYPTOS
10 Æ NILVS SC
11 N ADVENTVI AVG AFRICAE
12 N RESTITVTORI ACHAIAE
13 Æ EXERCITVS GERMANICVS SC
14 N PMTRPCOSIII
15 Æ LOCVPLETATORIORBISTERRARVM SC
16 N PMTRP COSIII SALVSAVG
17 Æ ANTONINVS AVGPIVSPP COS IIII S C ASIA
18 Æ CAPPADOCIA S C
19 Æ REXARMENIIS DATVS SC
20 Æ REXQVADIS DATVS
21 Æ FAVSTINA DIVAAVG PVELLAEFAVSTINIANAE
22 N IMPCAESMAVRELANTONINVSAVG CONCORDIAEAVGVSTORTRPXV COSIII
23 Æ TRPXXXIIMPVIICOSIIIPP DEGERM
24 Æ TRPXXXIIMPVIIICOSIIIPP DESARM
25 Æ FAVSTINA AVGVSTA FORTVNAE MVLIEBRI
26 Æ MCOMMODANTPFELIXAVGBRITPP COLLANCOMPMTRPXVIMPVIII S C COSVIPP
27 Æ HERCVLIROMANOAVG
28 N LAELAVRELCOMMAVGPFEL HERCROMCOND COSVIIPP
29 Æ IMPCAESPHELPPERTINAVG MENTILAVDANDAE
30 Æ IMPCAESCPESCNIGERIVSTVSAVG FELICITASTEMPORVM
31 N SEVERVSPIVSAVGPMTRPX FELICITAS SAECVLI
32 Æ DIVIMPIIPPMTRPIIICOSIIPP S.C
33 Æ ANTONINVSPIVSAVGGERM PMTRPXVIIICOSIIIIPP
33 Æ B OI
34 Æ PMTRPXVIICOSIIIIPP
35 Æ PMTRPXVIICOSIIIIPP
36 Æ DIVOANTONINOMAGNO CONSECRATIO
37 Æ ΜΑΚΕΔΟΝΩΝ ΠΡΩΤΗΣ
39 Æ ΤΑΡΑΣ
40 Æ ΑΡΕΘΟΣΑ ΣΥΡΑΚΟΣΙΩΝ
41 Æ ΑΘΕ ΝΕΣ ΤΩΡ ΜΝΑ ΣΕ ΑΣ
42 Æ ΓΕ ΣΙΠ
43 Æ ΟΜΗΡΟΣ ΣΜΥΡΝΑΙΩΝ
44 Æ
45 Æ MPCORDIANVSPIVSFELAVG PMS COLVIM ANIIII
46 Æ ΣΥΡΑΚΟΣΙΟΙ ΓΕΛΩΝΟΣ Ε ΒΛ
47 N ΟΛΥΜΠΙ

NUMISMATOLOGY. *PLATE CCCCXXIII.*

6



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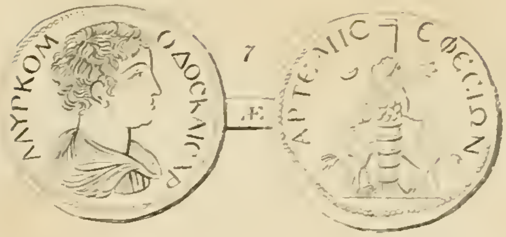
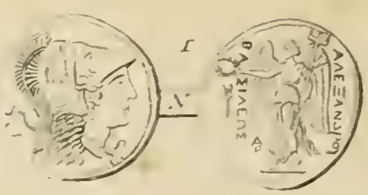
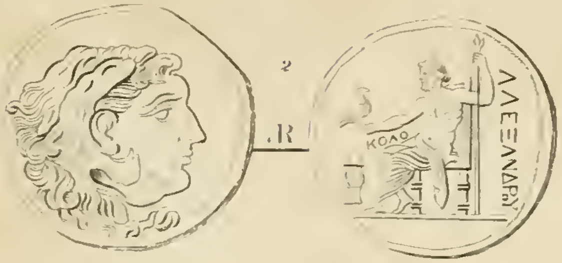


1



2



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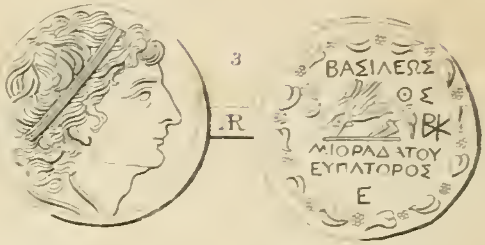
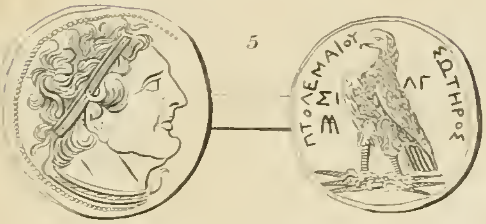


5



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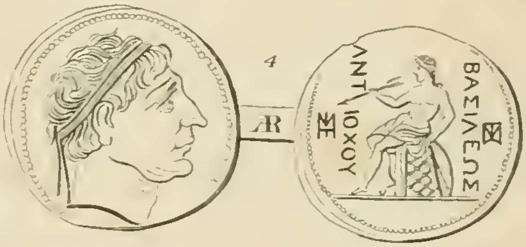
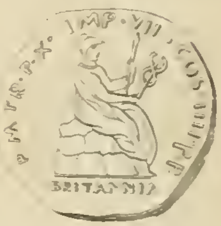
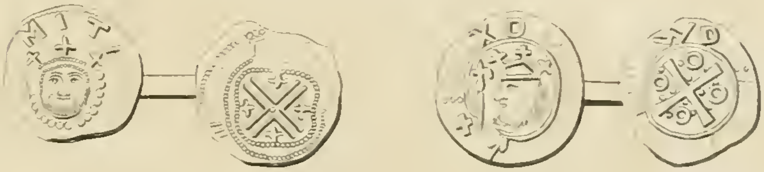


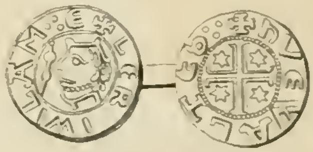
Reverse of a British coin of Severus.



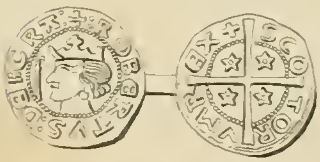
Antient pennies supposed Scottish.



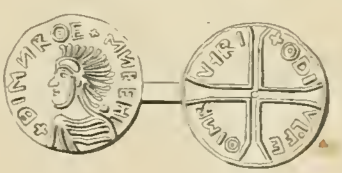
A penny of William of Scotland.



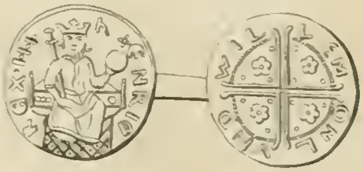
A penny of Robert the Great.



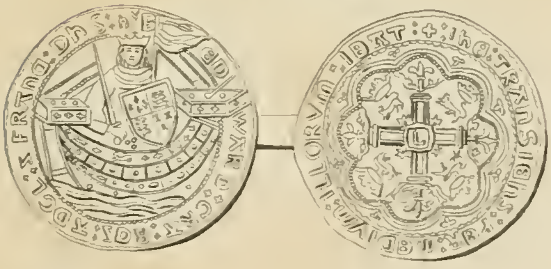
An Irish penny.



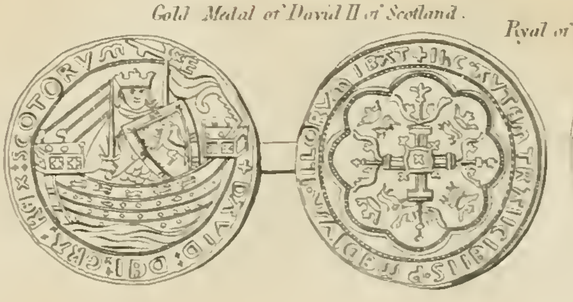
Gold penny of Henry III.



Large noble of Edward III.

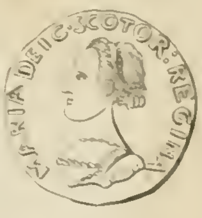


Gold Medal of David II of Scotland.



DAVID·DEI·GRA·REX·SCOTORVM
IHC·TRANSIENS·PER·MEDIVM·ILLORVM·IBAT

Ryal of Queen Mary of Scotland.



R. [illegible]

OBSERVATORY. PLATE CCCCXXV.

EDINBURGH OBSERVATORY

Elevation *Fig 1*

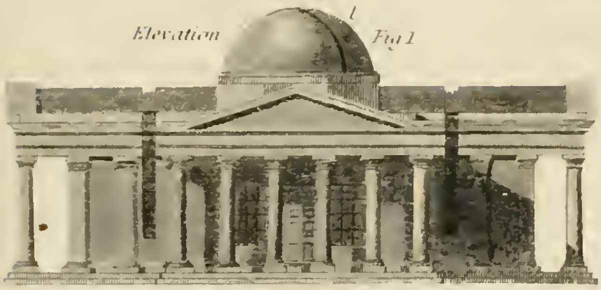
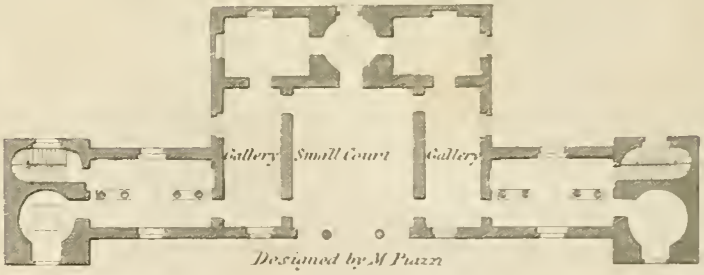


Fig 3.

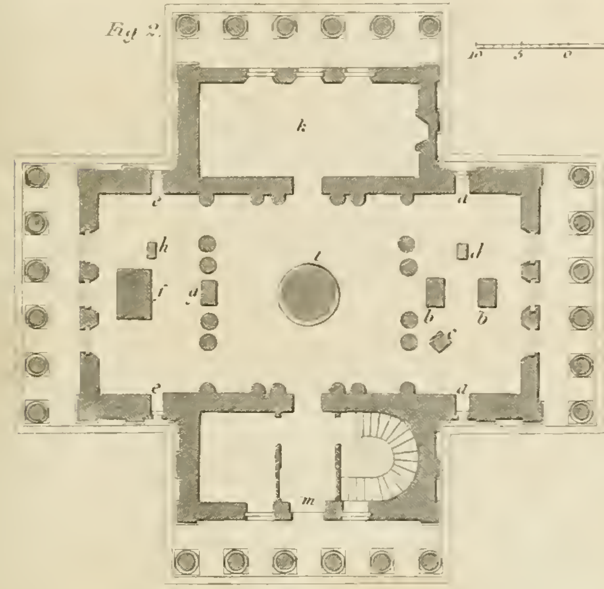
PLAN OF THE NEW OBSERVATORY OF NAPLES



Designed by M Piazzi

Ground Plan

Fig 2.



Scale of Feet for Fig 1 & 2

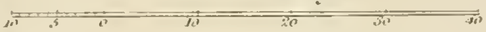


Fig 4

PLAN OF THE OLD OBSERVATORY AT NAPLES

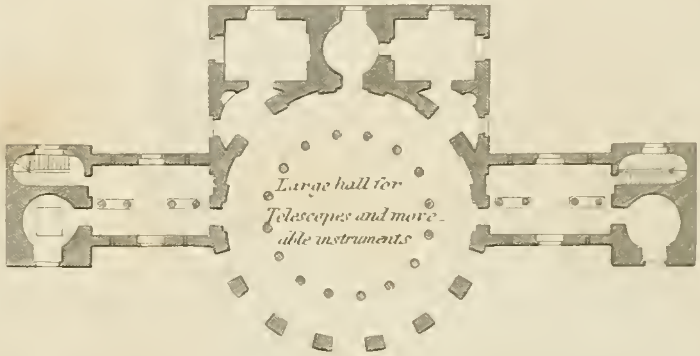
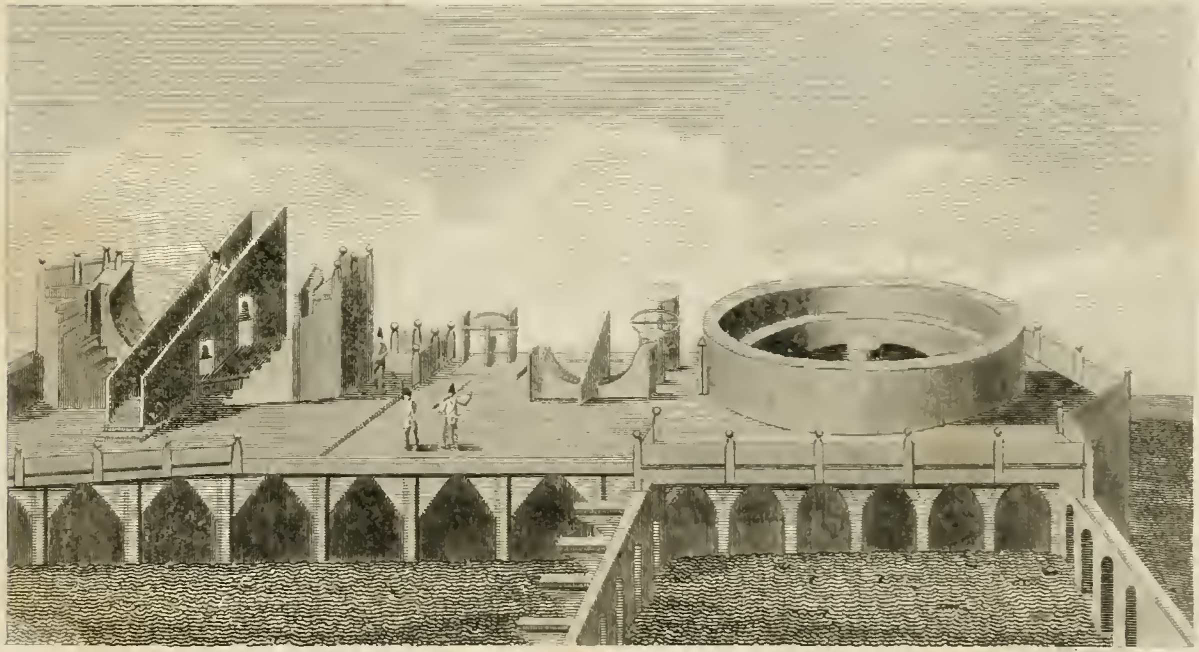


Fig 5.

BRAMINS OBSERVATORY AT BENARES



OBSERVATORY & ODOMETER. *PLATES CCCCXXIV & CCCCXXVI.*

Fig 1

ODOMETER *Natural Size*

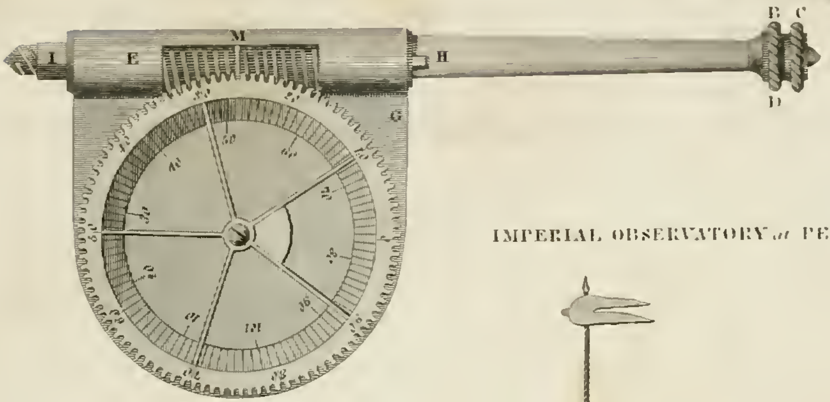
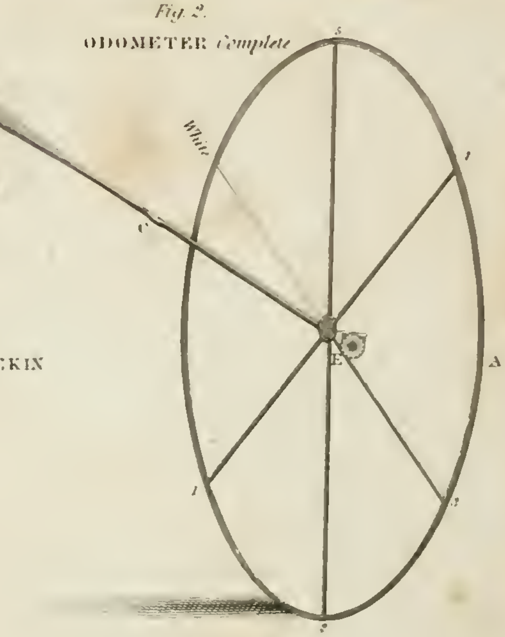
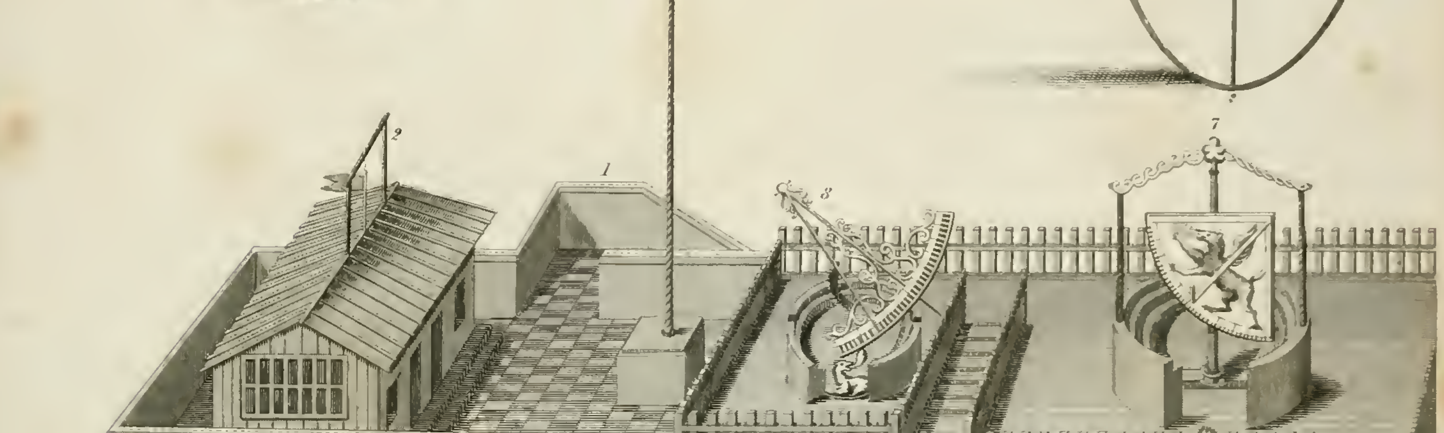


Fig. 2.

ODOMETER *Complete*



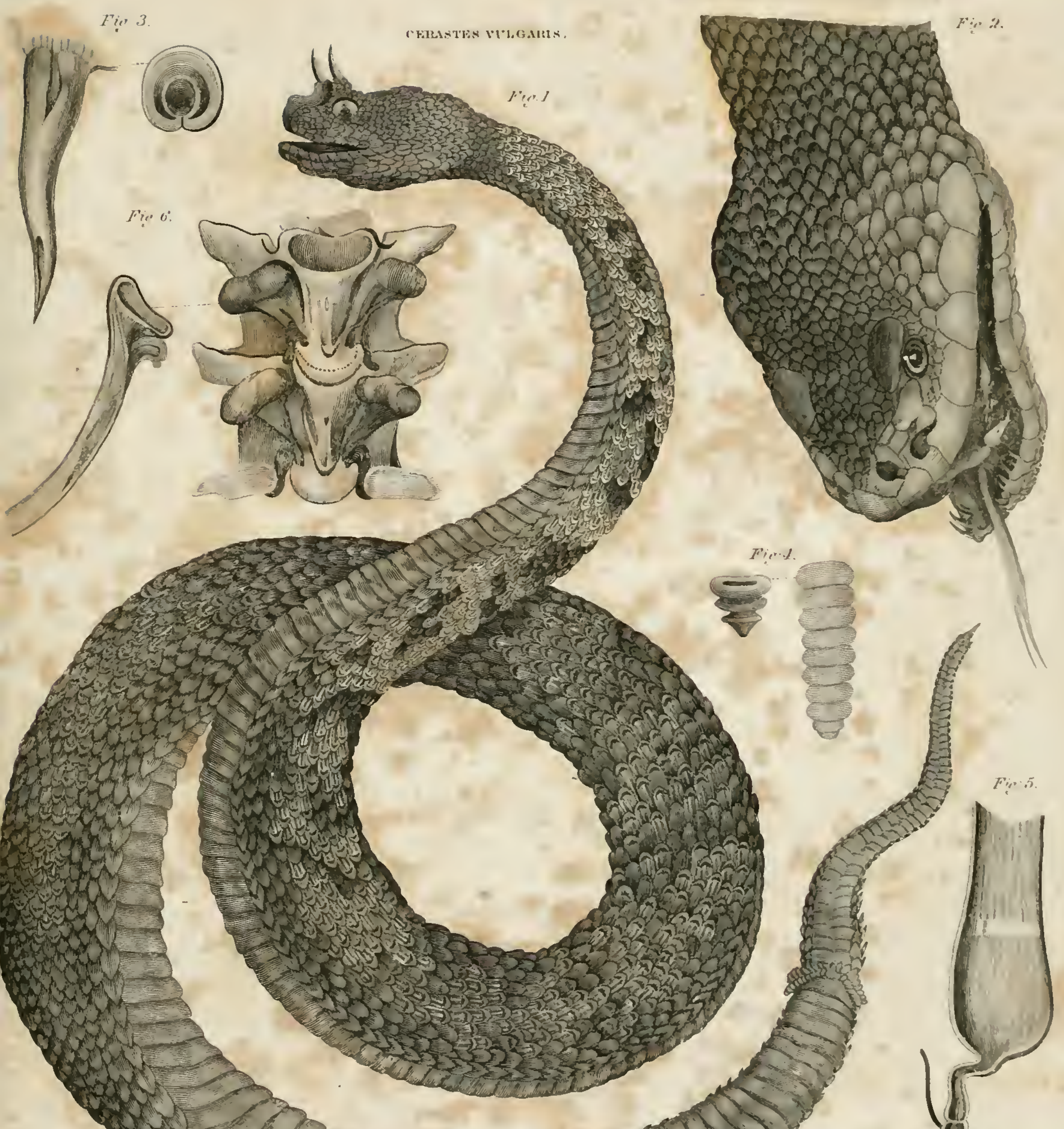
IMPERIAL OBSERVATORY *at* PEKIN



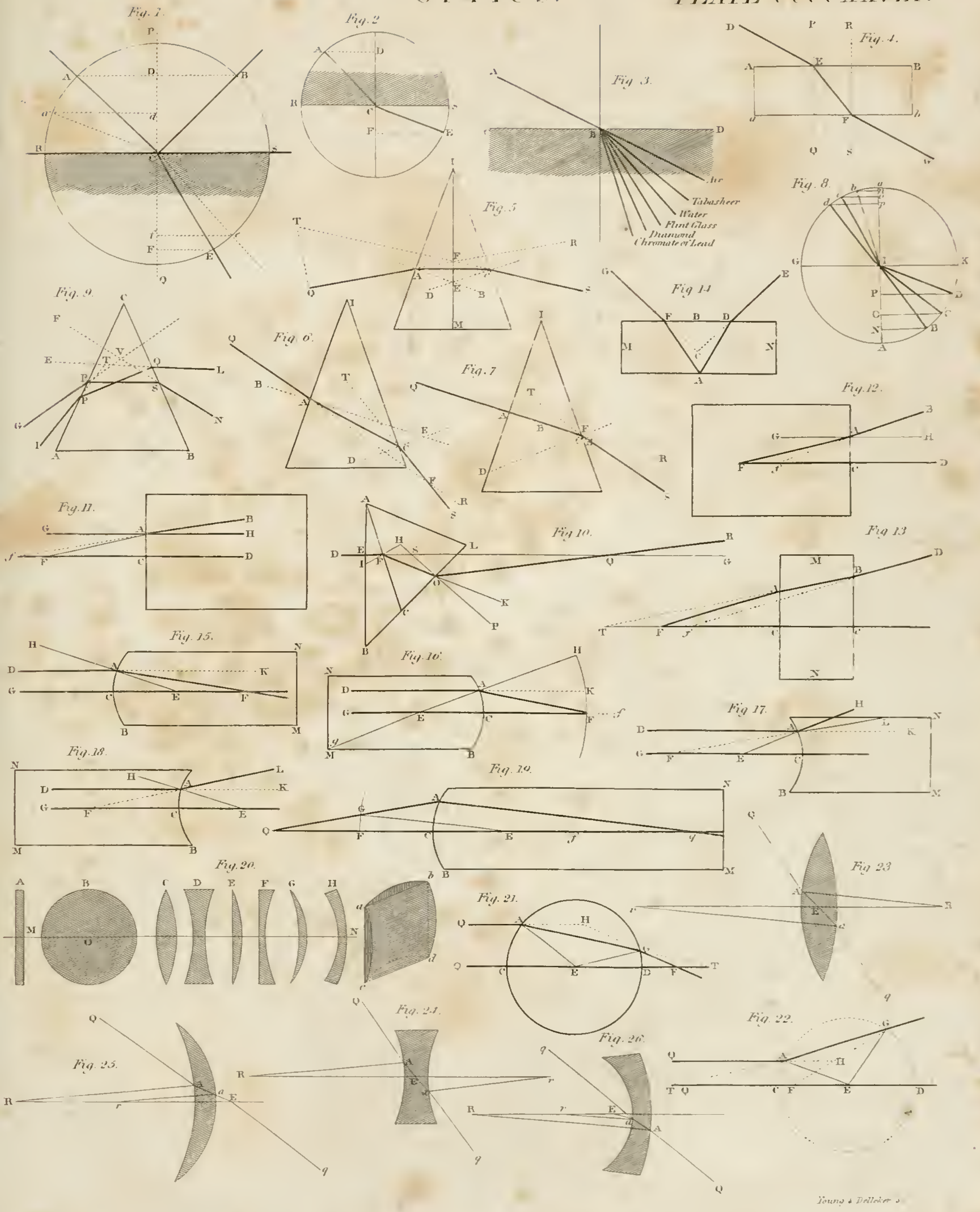
1 The Stairs of the Observatory 2. A Retiring Room for the Observers 3 An Equinoctial Sphere 4 A Celestial Globe 5 An Armillary Sphere 6 An Azimuthal Horizon 7 A Quadrant 8 A Sextant

OPHIOLOGY

PLATE CCCCXXVII

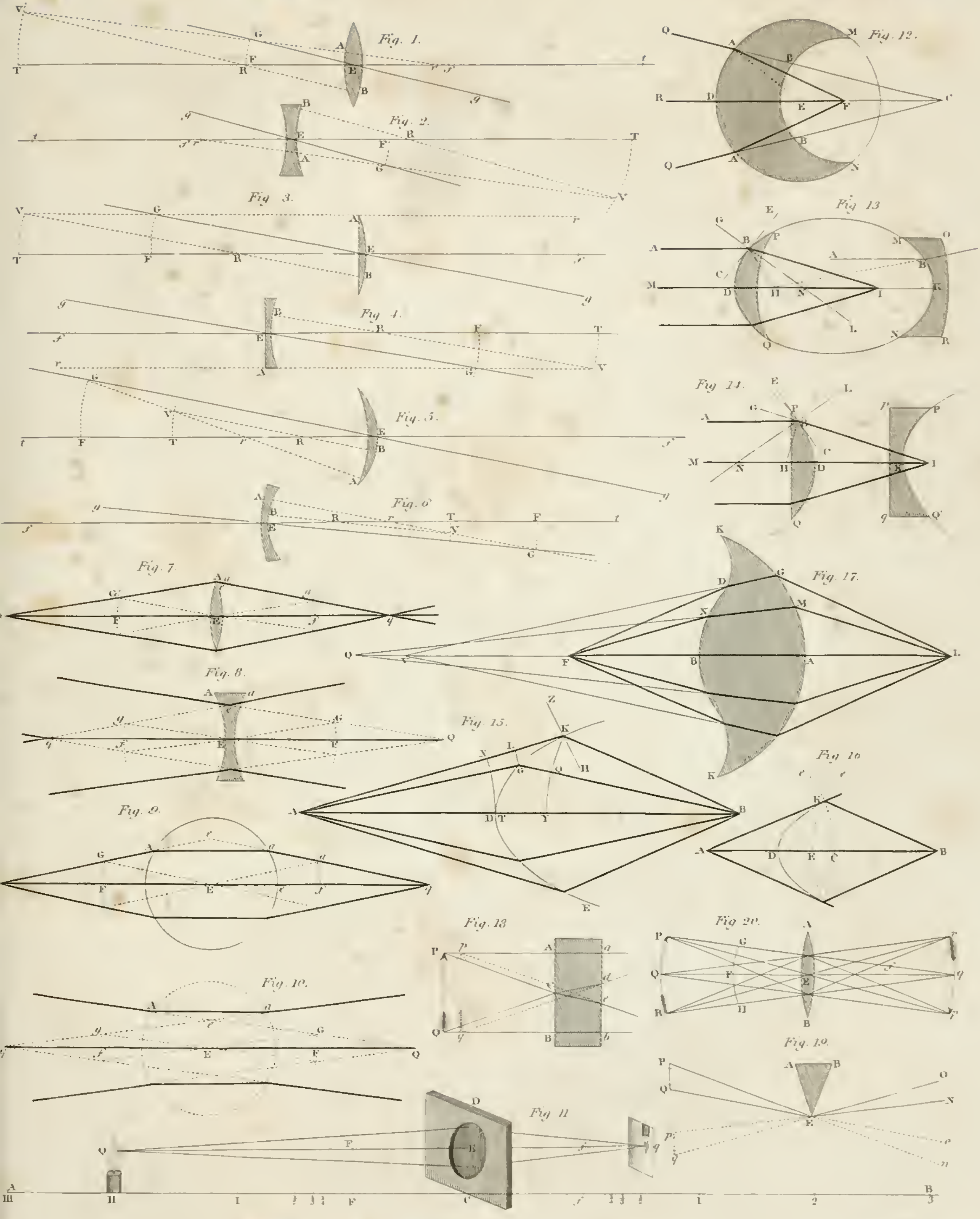

TRIGONOCEPHALUS LANCEOLATUS.
CERASTES VULGARIS.
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.

OPTICS. PLATE CCCCXXVIII.



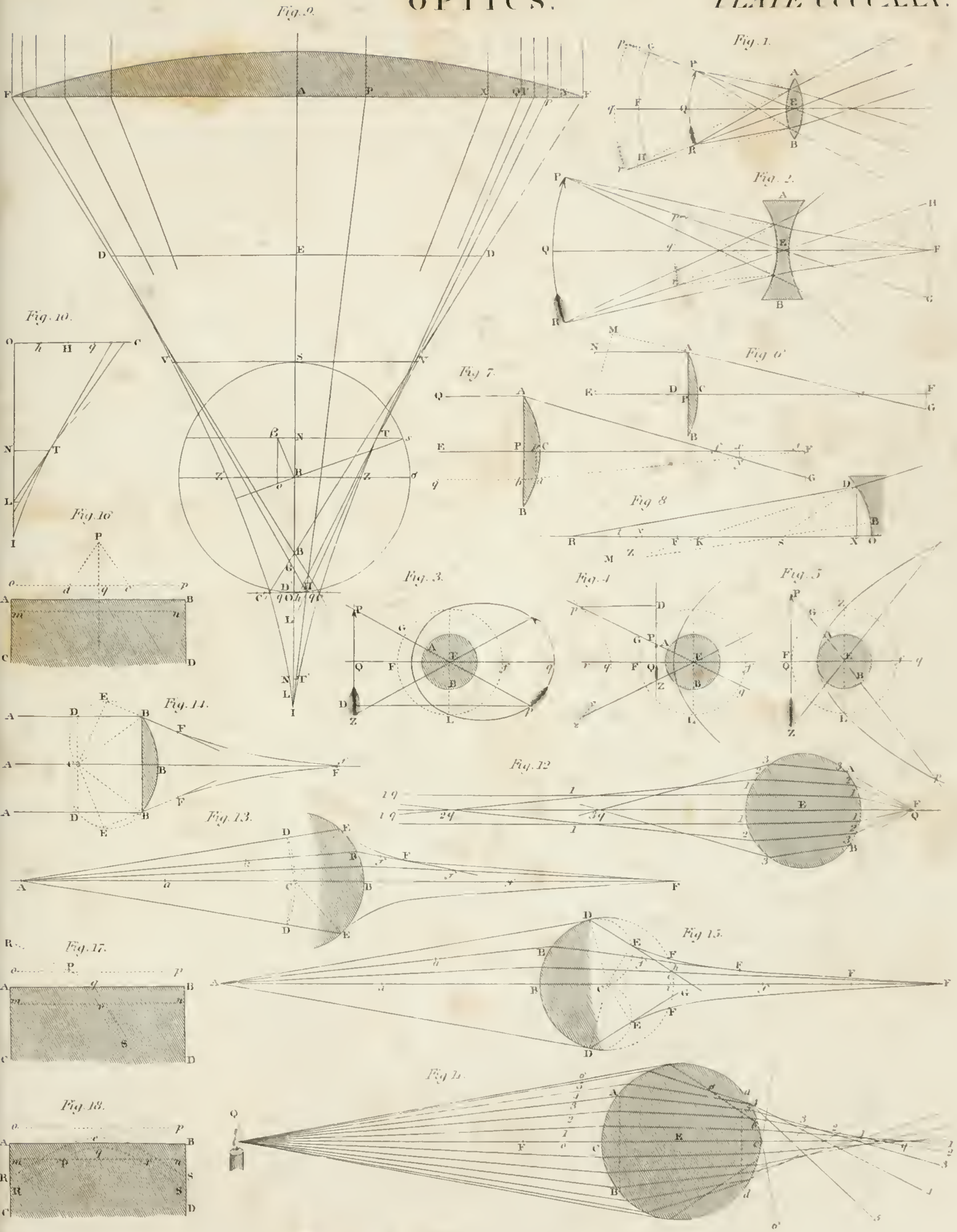
Young & Delleker sc.

OPTICS. PLATE CCCCXXIX.



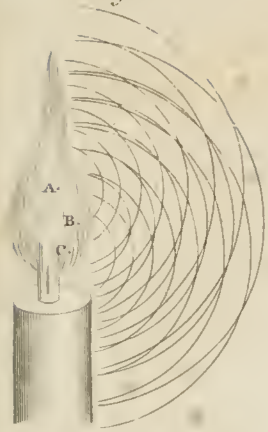
OPTICS.

PLATE CCCCXXX.



OPTICS. *PLATE CCCCXXXI.*

Fig. 1.



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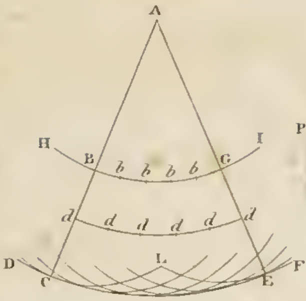

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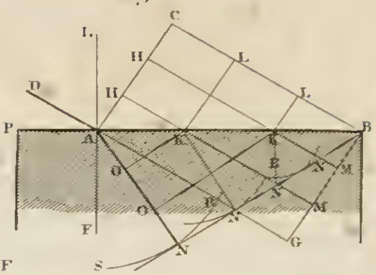

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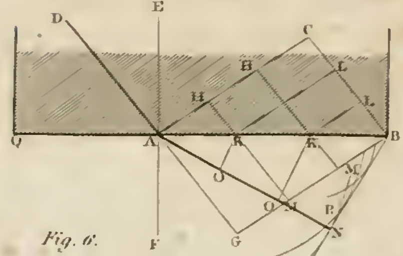


Fig. 6.

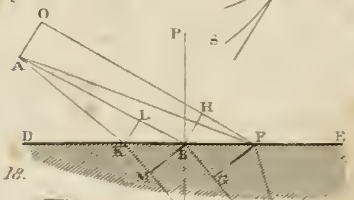
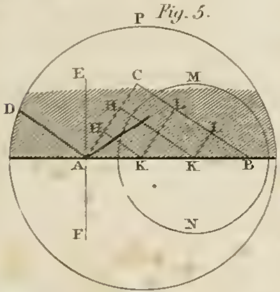


Fig. 5.



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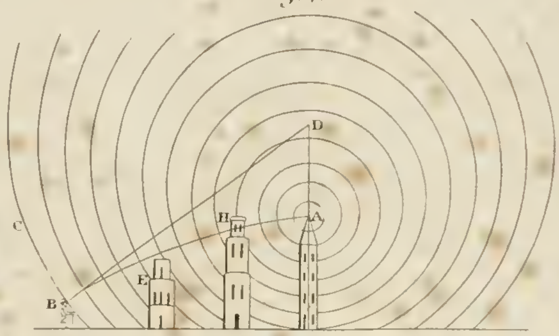

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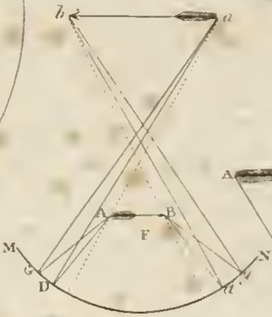

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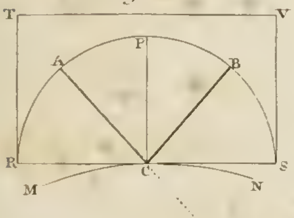
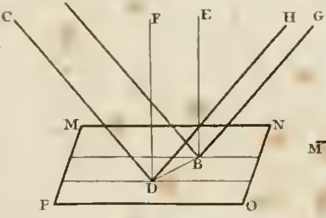


Fig. 9.



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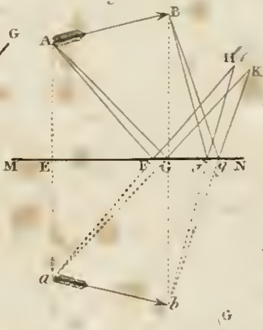

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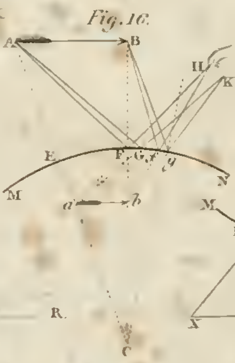

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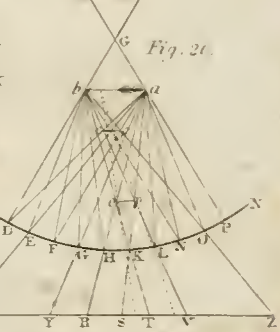


Fig. 10.

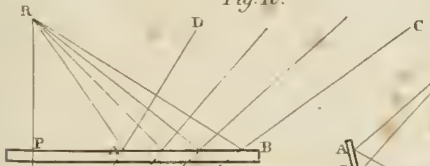
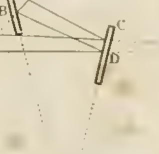


Fig. 14.



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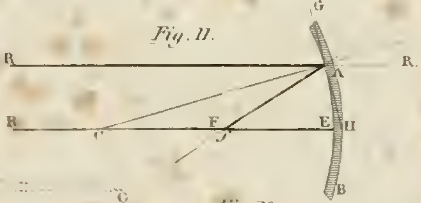

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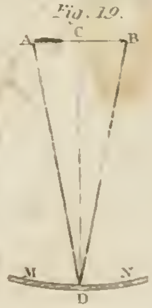

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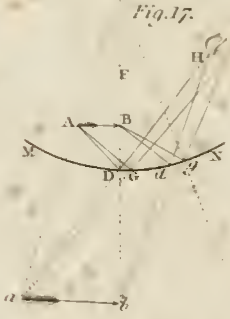

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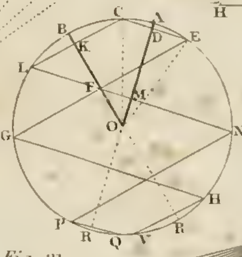

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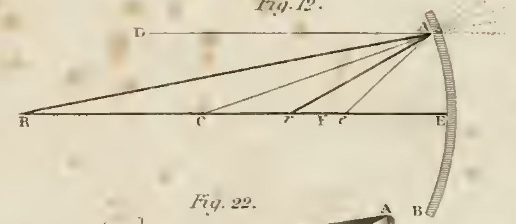

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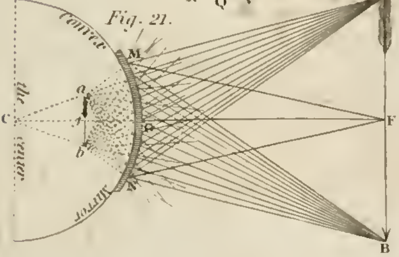

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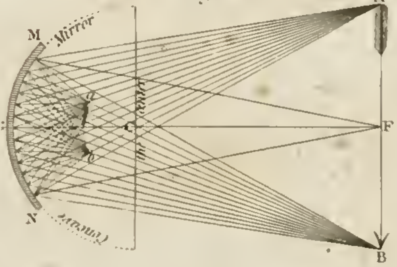

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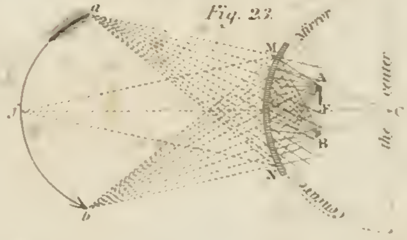

OPTICS.

PLATE CCCCXXXII.

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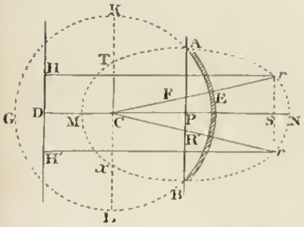

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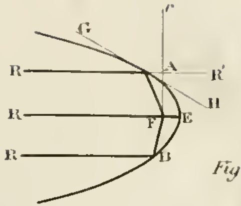
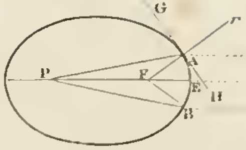


Fig. 3.



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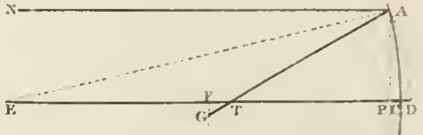

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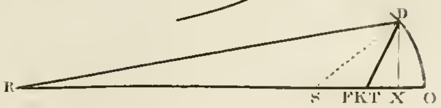

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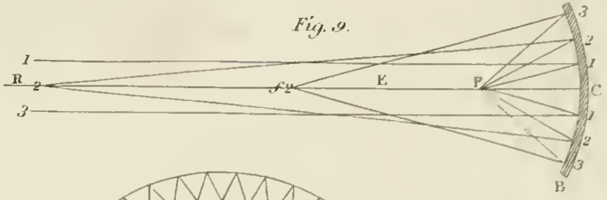
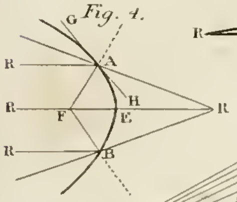


Fig. 4.



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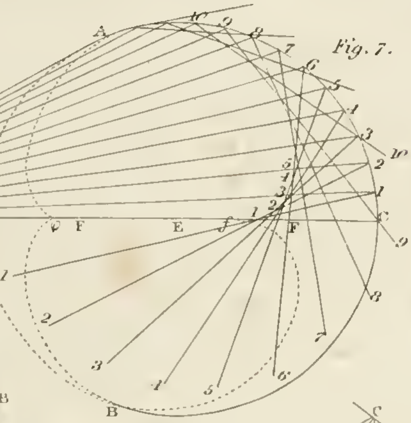

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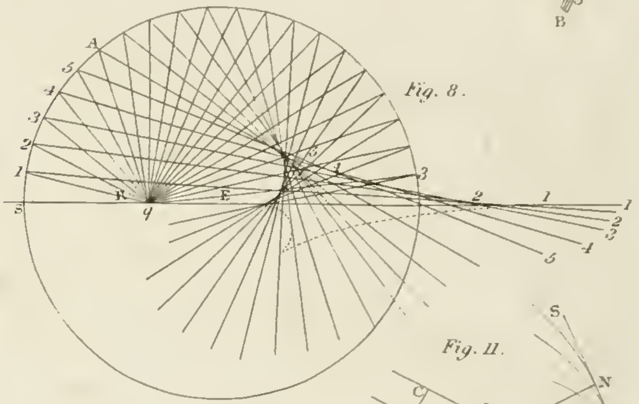

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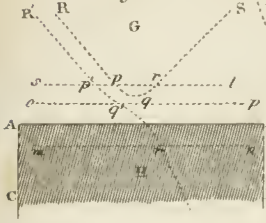

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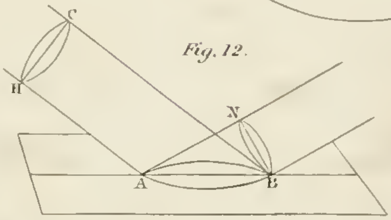

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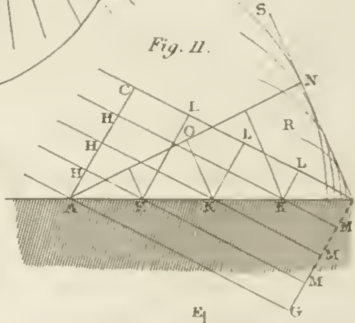

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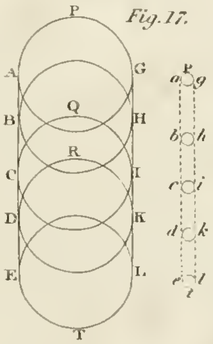

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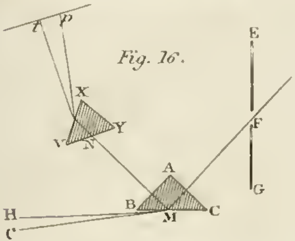

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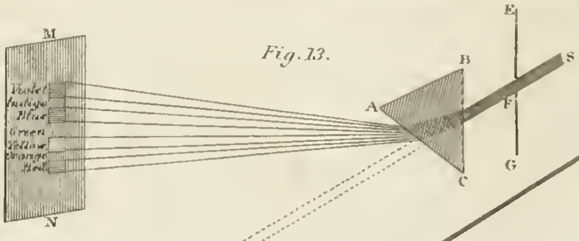

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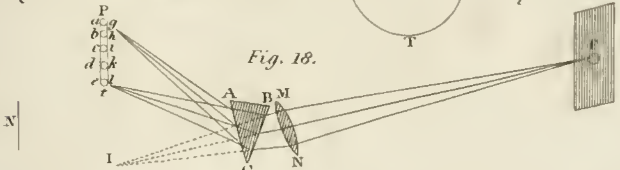

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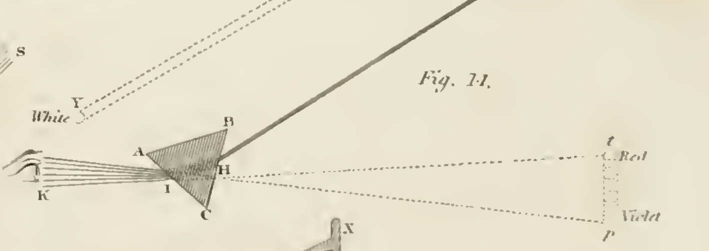

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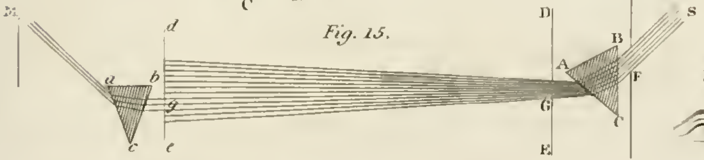

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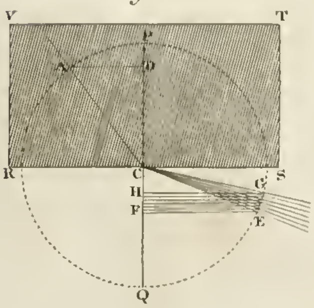

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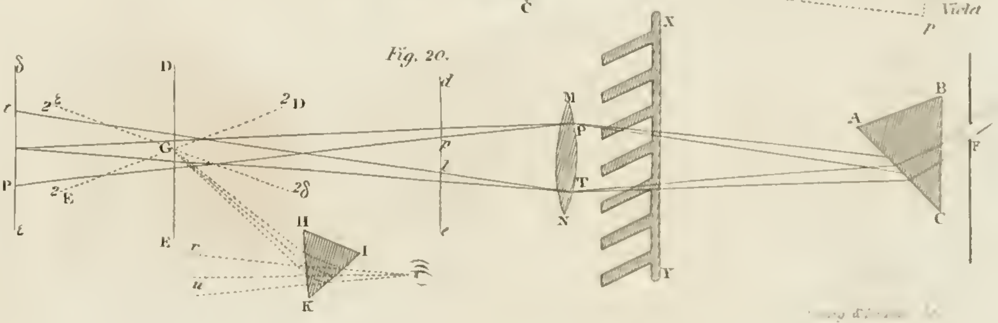
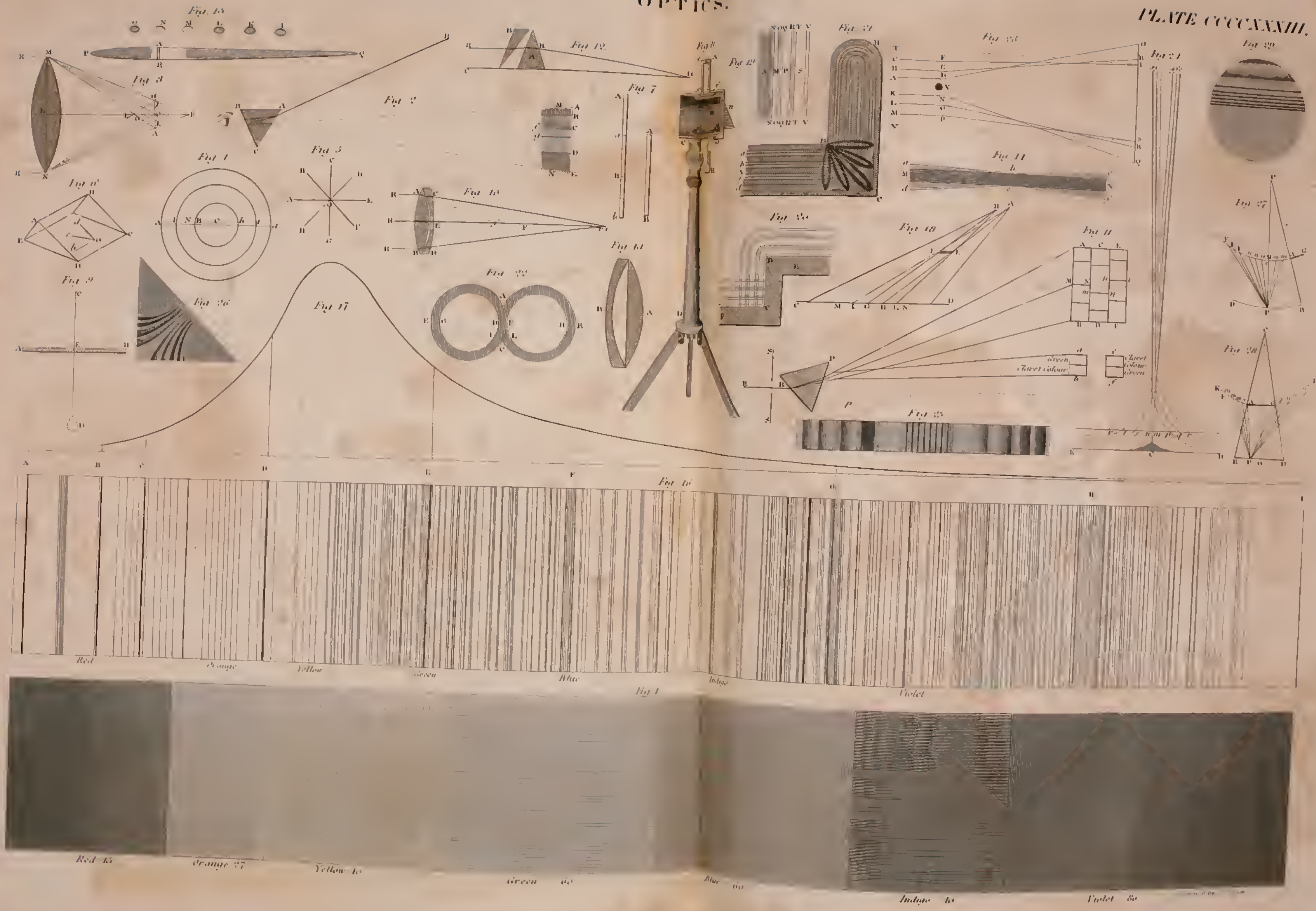


OPTICS.

PLATE CCCCXXXIII.



OPTICS PLATE CCCCXXXIV

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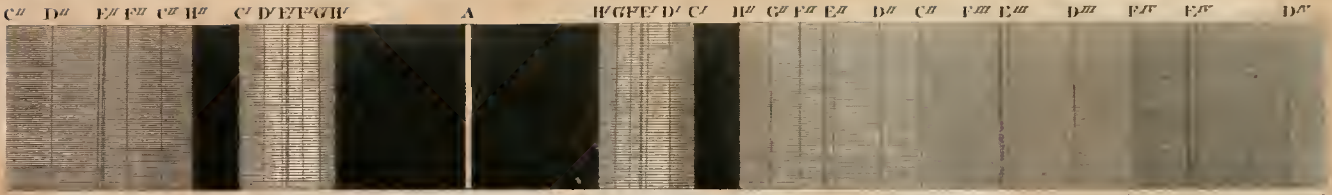

C^{II} D^{II} E^{II} F^{II} G^{II} H^{II}
C^{I} D^{I} E^{I} F^{I} G^{I} H^{I}
A
H^{I} G^{I} F^{I} E^{I} D^{I} C^{I}
H^{II} G^{II} F^{II} E^{II} D^{II} C^{II}
F^{III} E^{III} D^{III}
F^{IV} E^{IV} D^{IV}

Fig. 2.

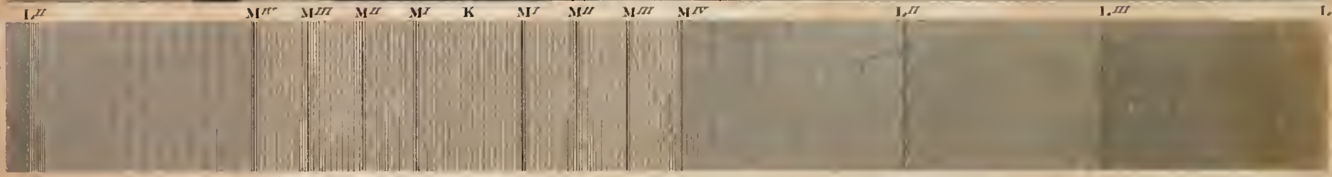
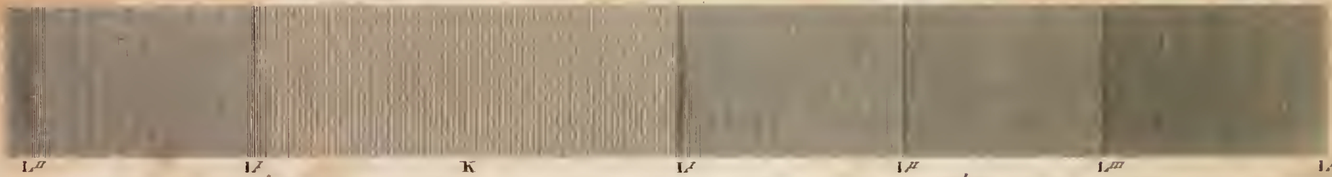

L^{II}
M^{IV} M^{III} M^{II} M^{I}
K
M^{I} M^{II} M^{III} M^{IV}
L^{II} L^{III} L^{IV}

Fig. 3.



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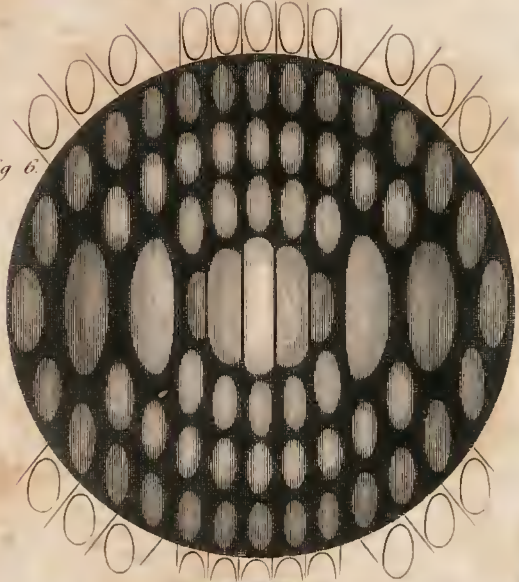

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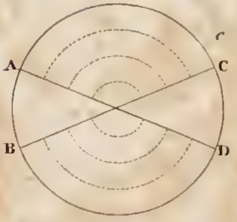

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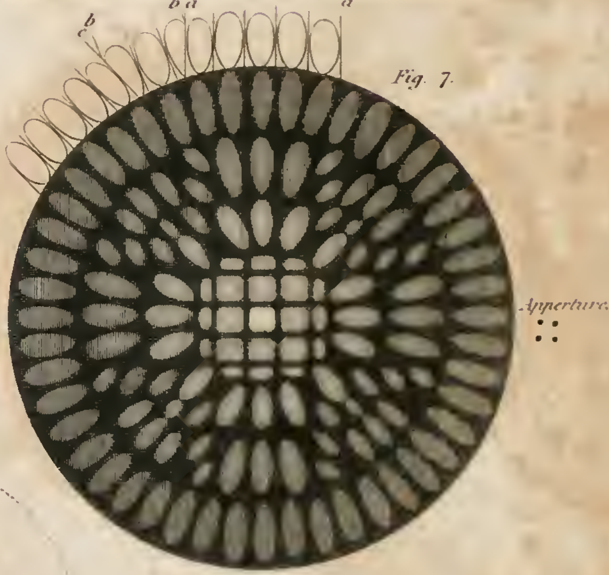

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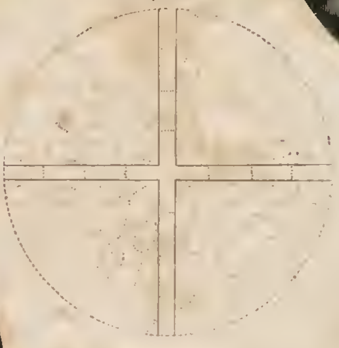

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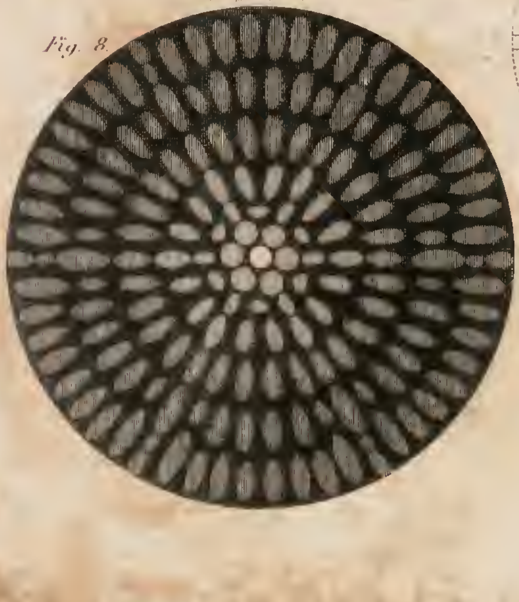

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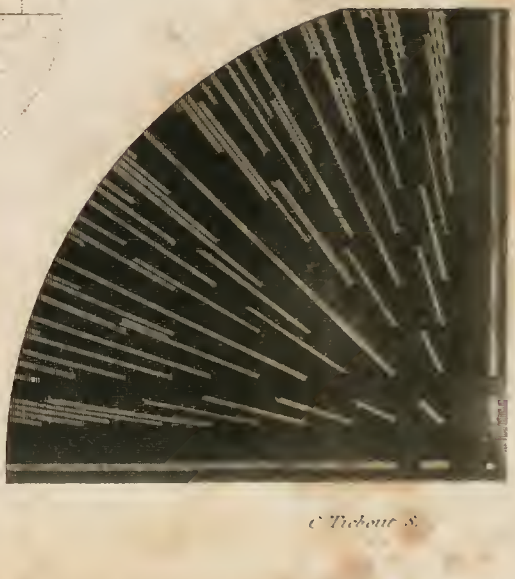


C Tiebout S.

OPTICS.

PLATE CCCCXXV

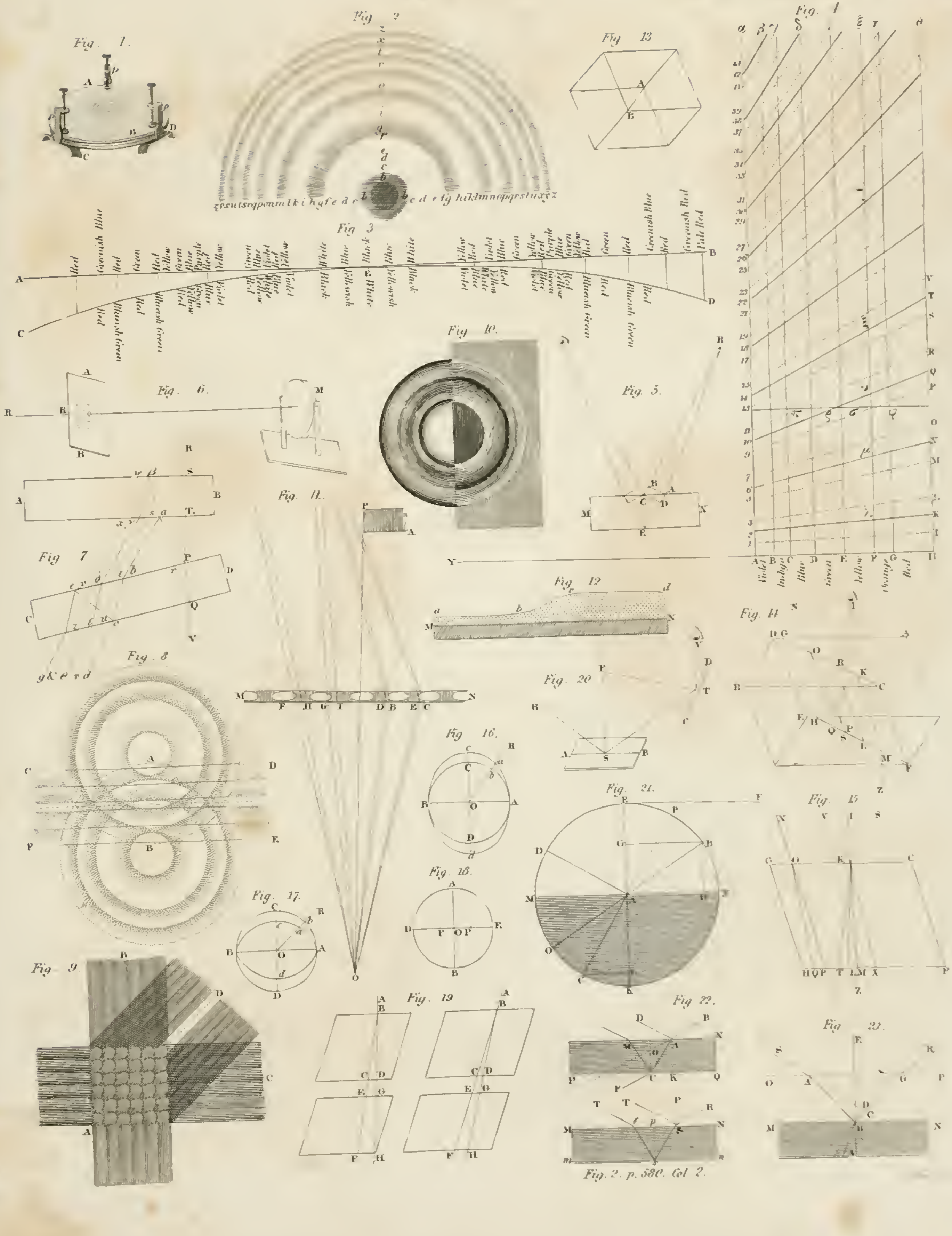
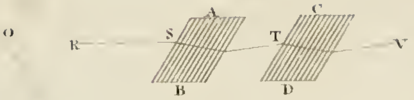


Fig. 2. p. 580. Col 2.

Fig. 2.



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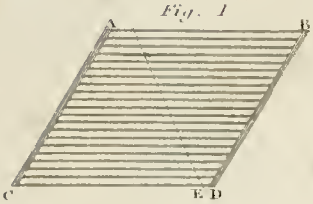

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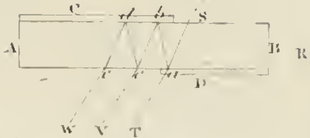

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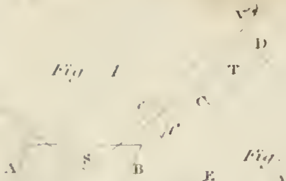

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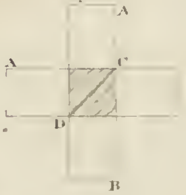

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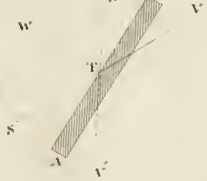

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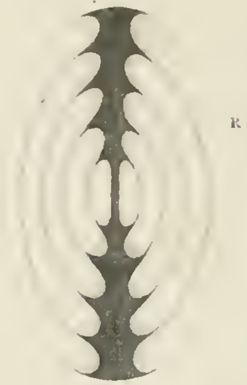

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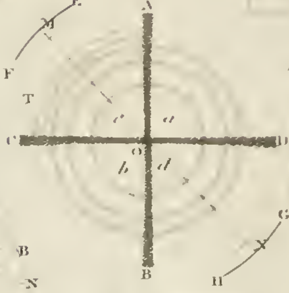

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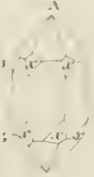

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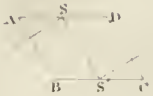

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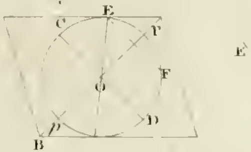

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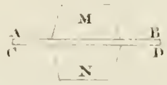

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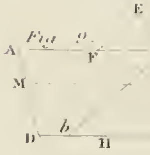

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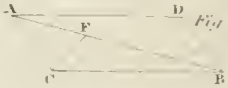

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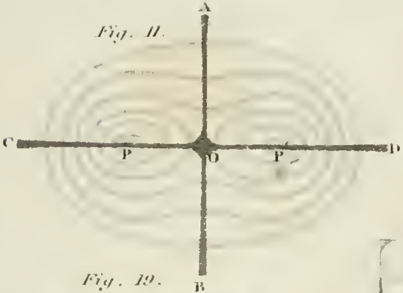

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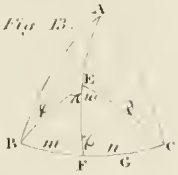

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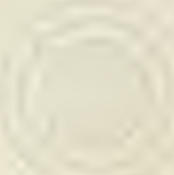

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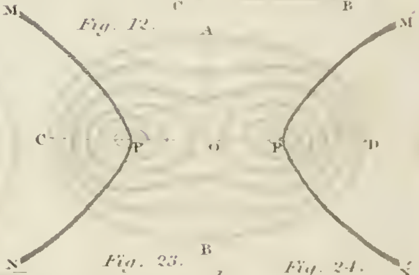

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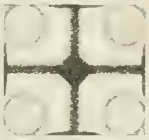

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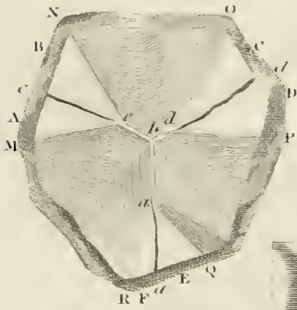

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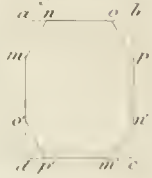

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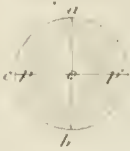

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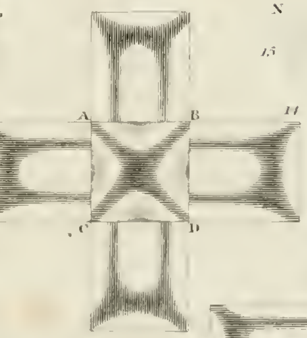

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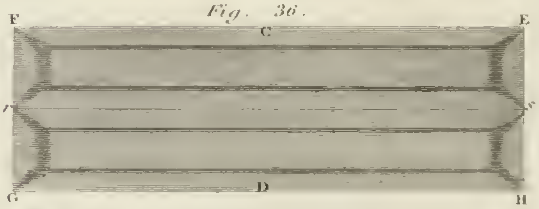

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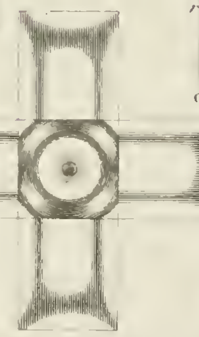

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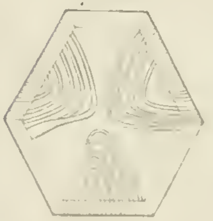

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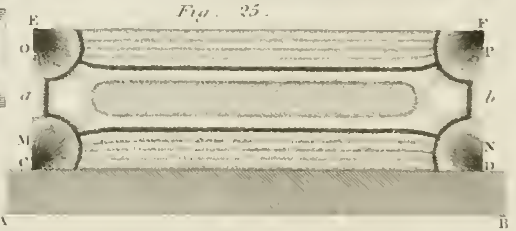

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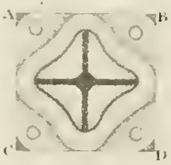

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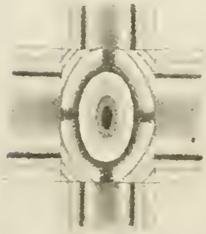

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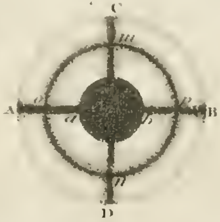

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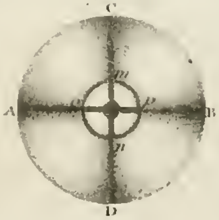

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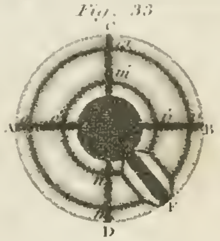

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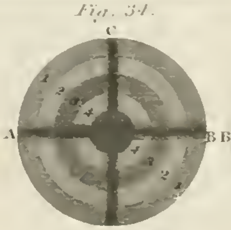

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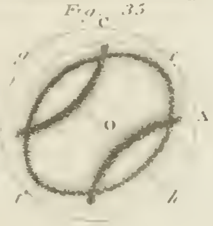

OPTICS. PLATE CCCCXXXVII.

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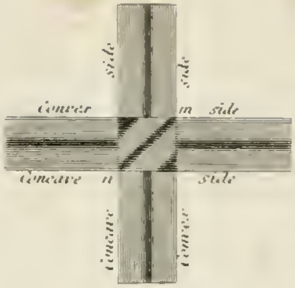

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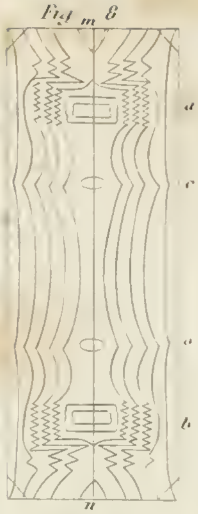

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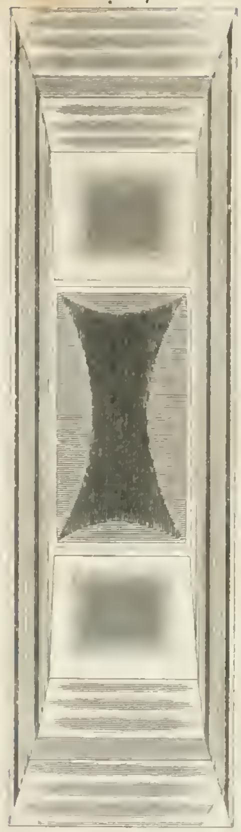

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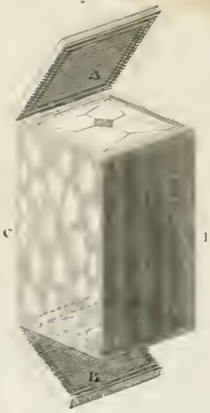

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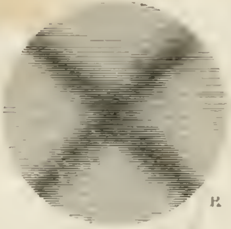

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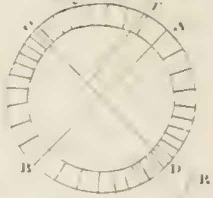

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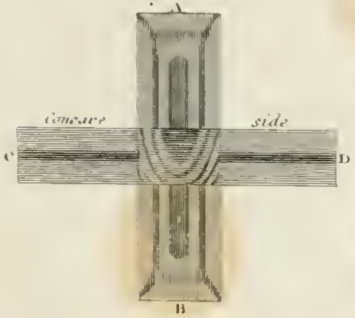

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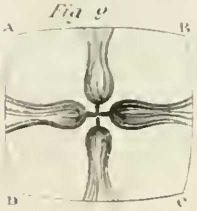

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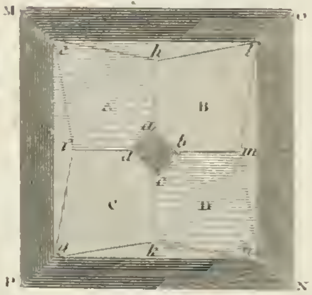

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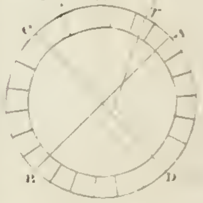

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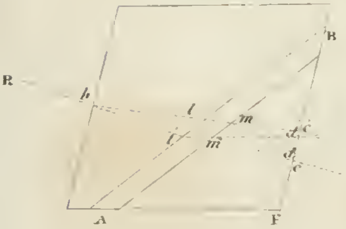

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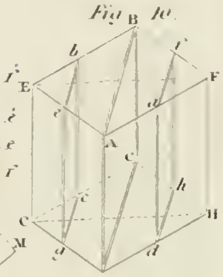

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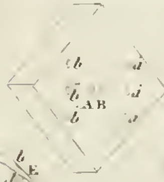

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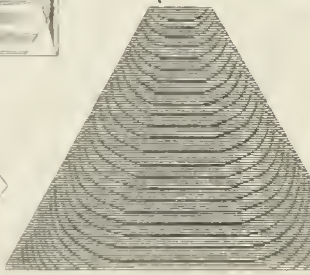

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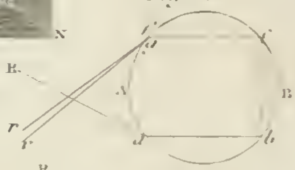

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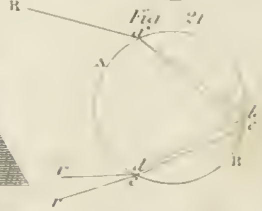

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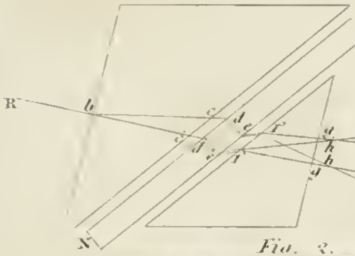

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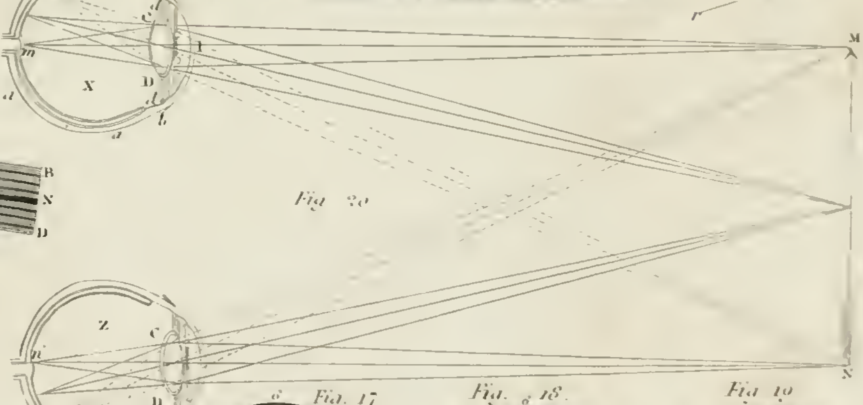
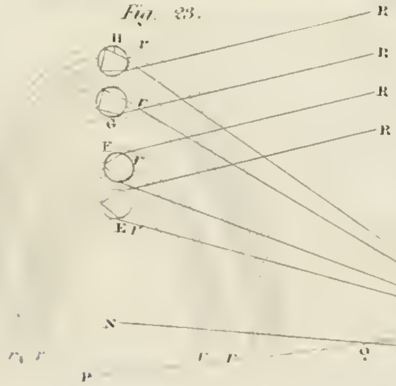


Fig. 2.

Fig. 23.



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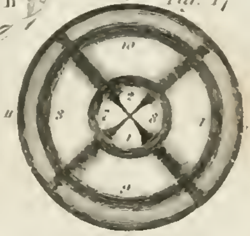

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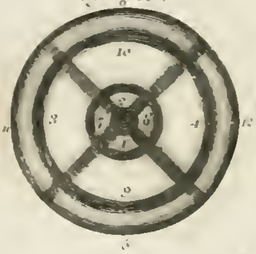

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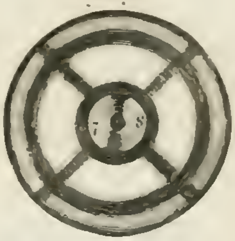

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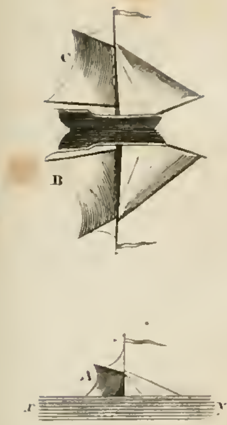

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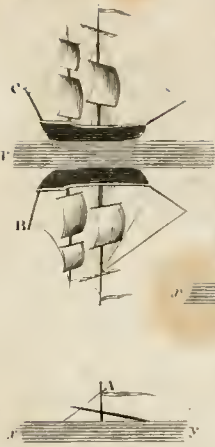

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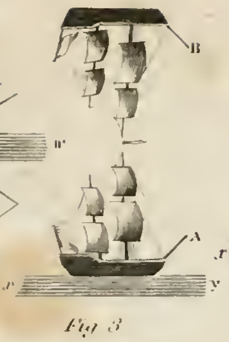

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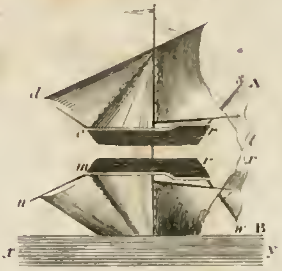

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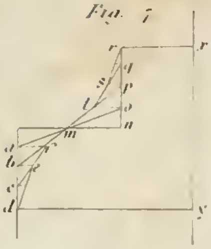

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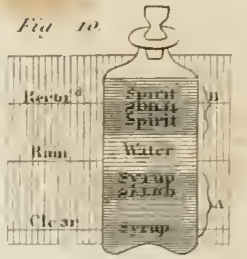

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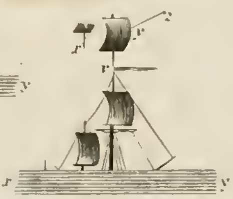

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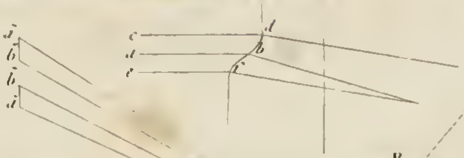

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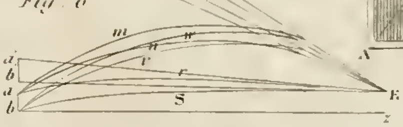

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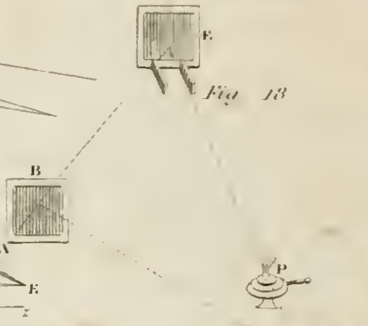

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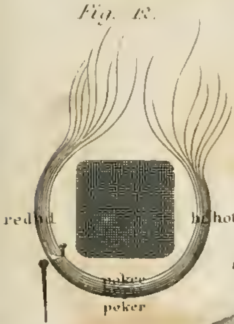

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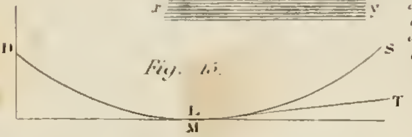

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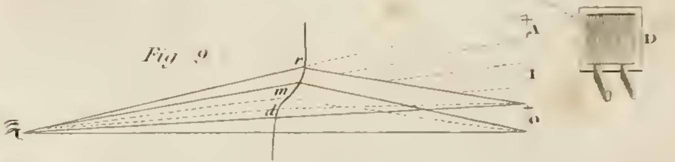

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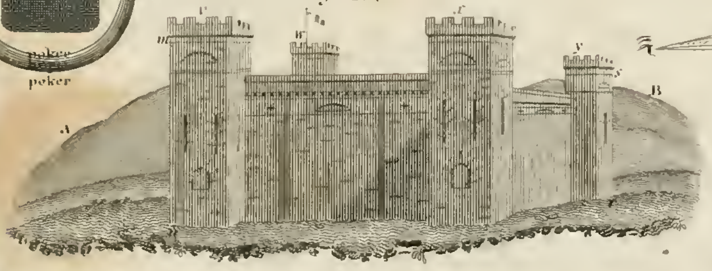

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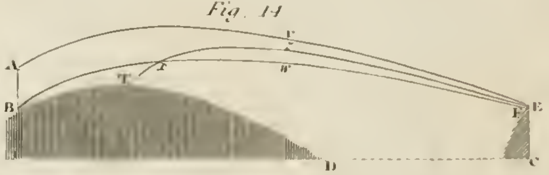

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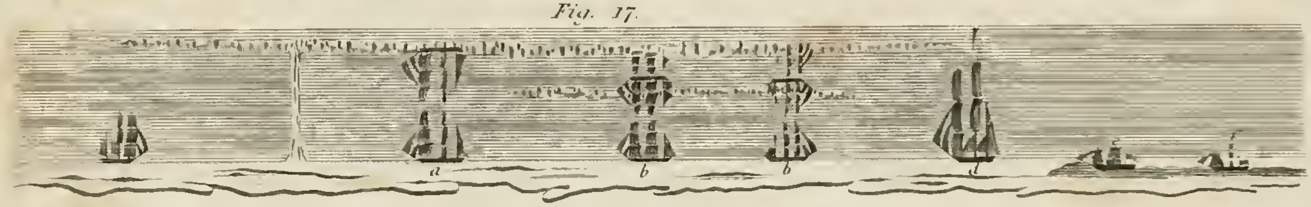

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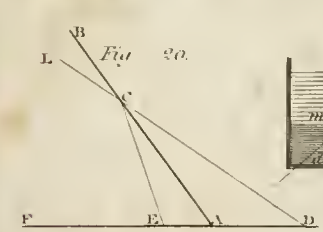

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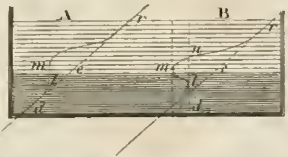

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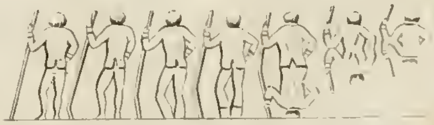
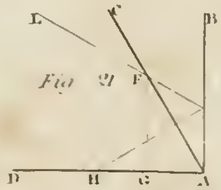


Fig. 21.



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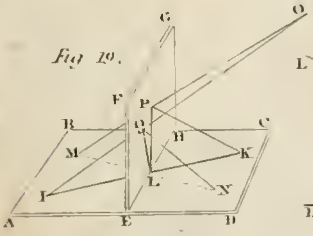

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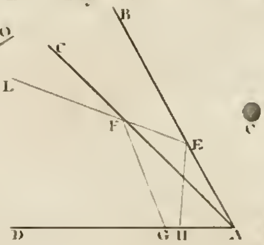

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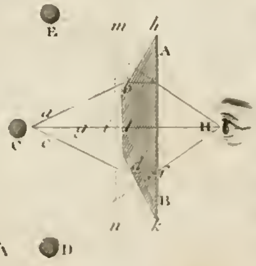

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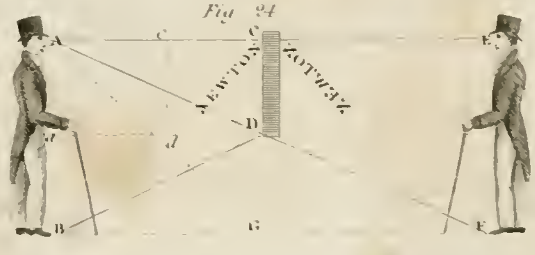
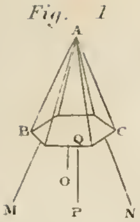


OPTICS

PLATE CCCCXXXIX.

Fig. 1



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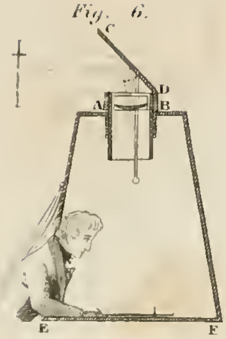

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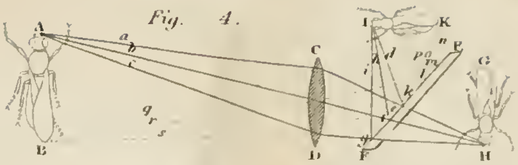

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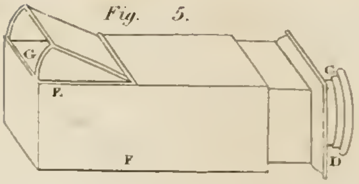

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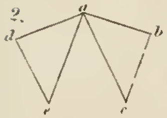


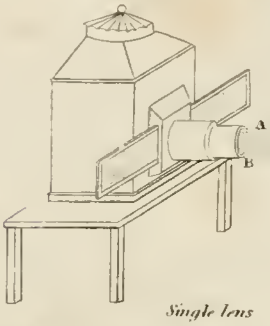
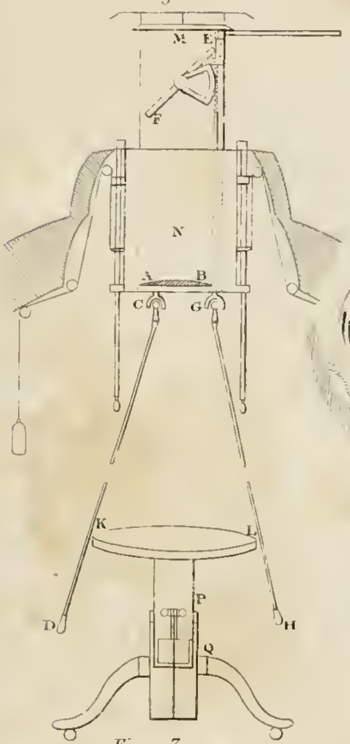


Fig 9.

Fig 8.



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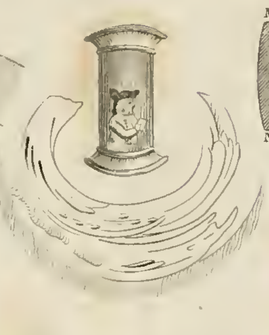


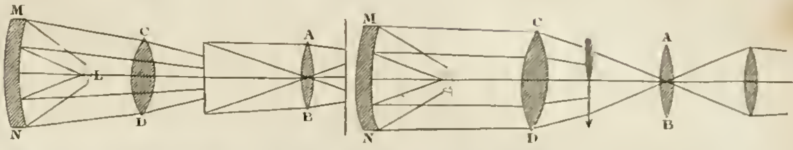
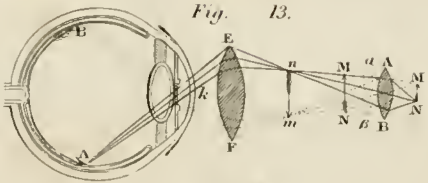

Single lens
Double lens

Fig. 10.

Fig. 13.



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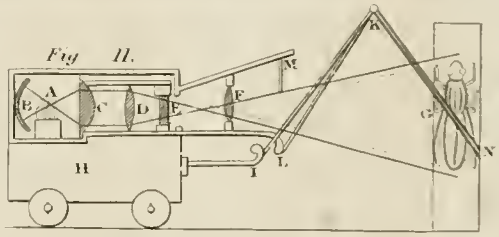

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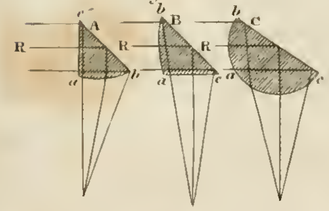

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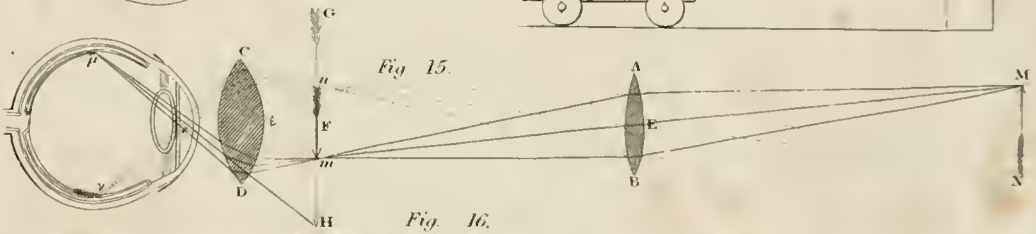

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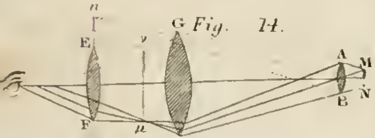

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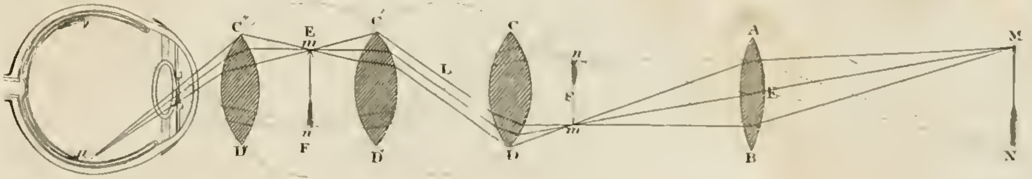

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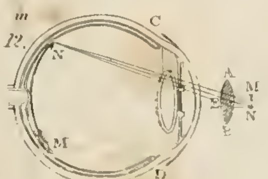

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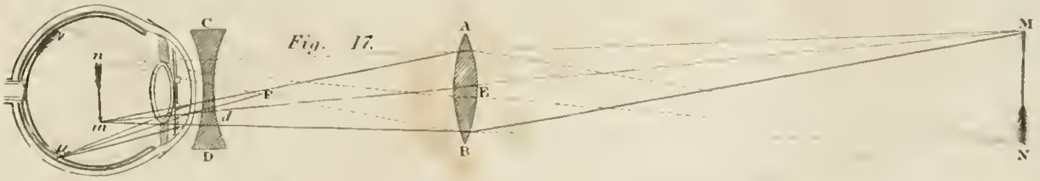

R Campbell Sc.

OPTICS.

PLATE CCCCXL.

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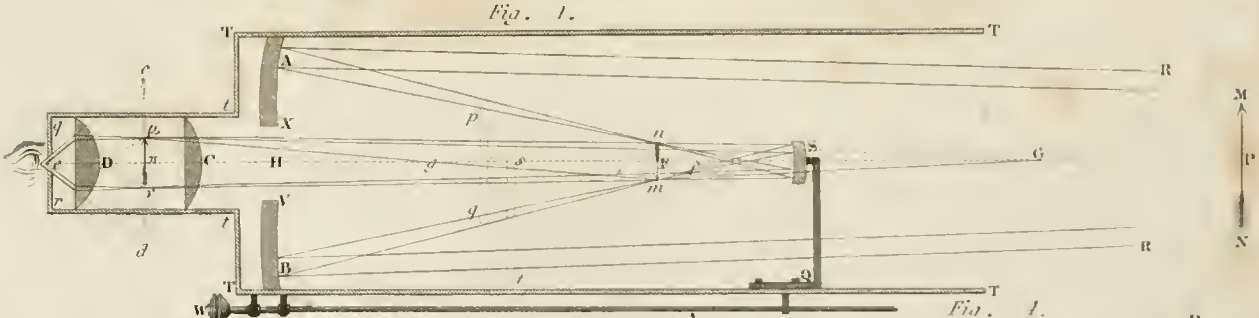


Fig. 4.

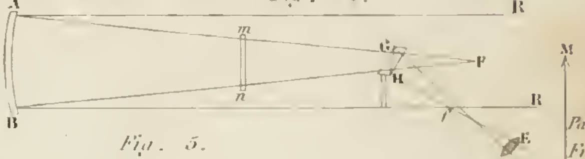
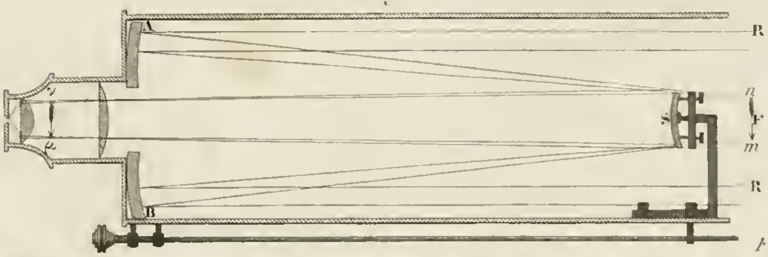


Fig. 2.



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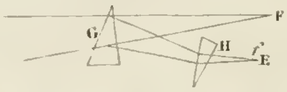

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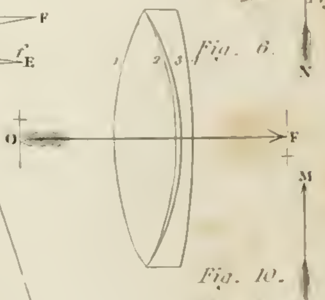
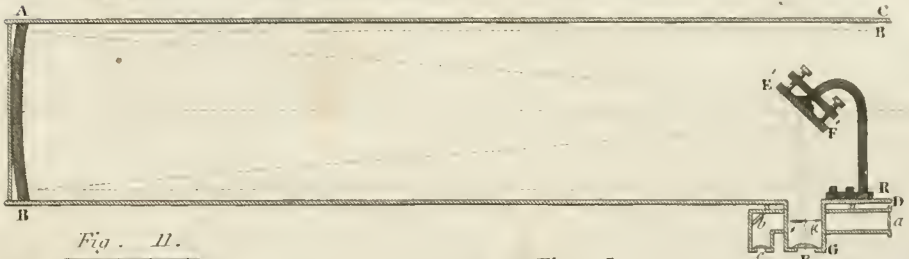


Fig. 3.



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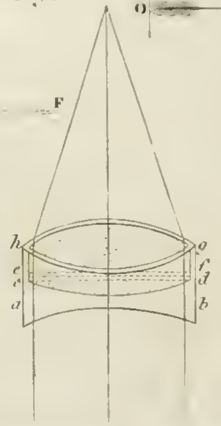

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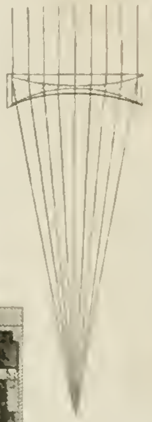

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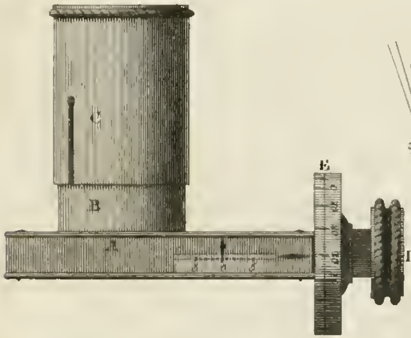

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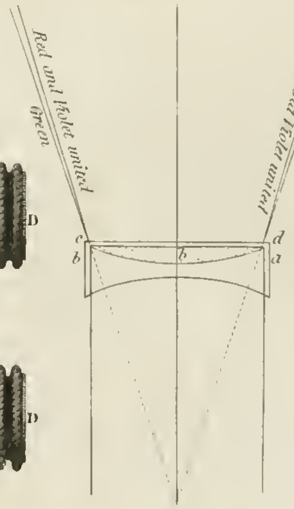


Fig. 8.

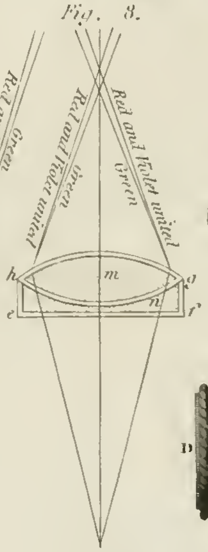
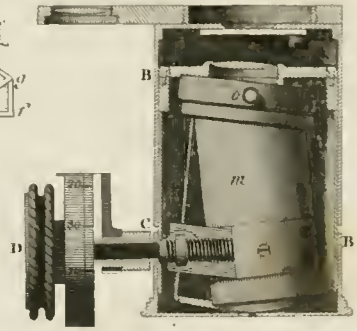


Fig. 13.



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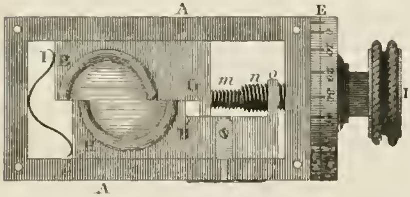

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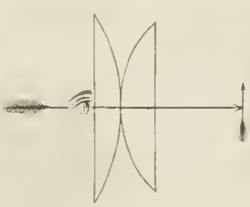

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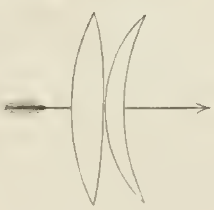

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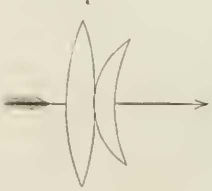

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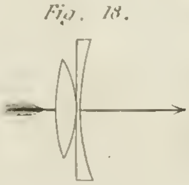

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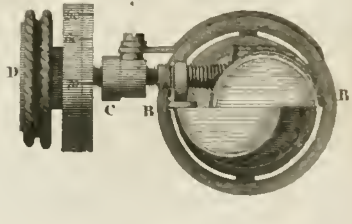
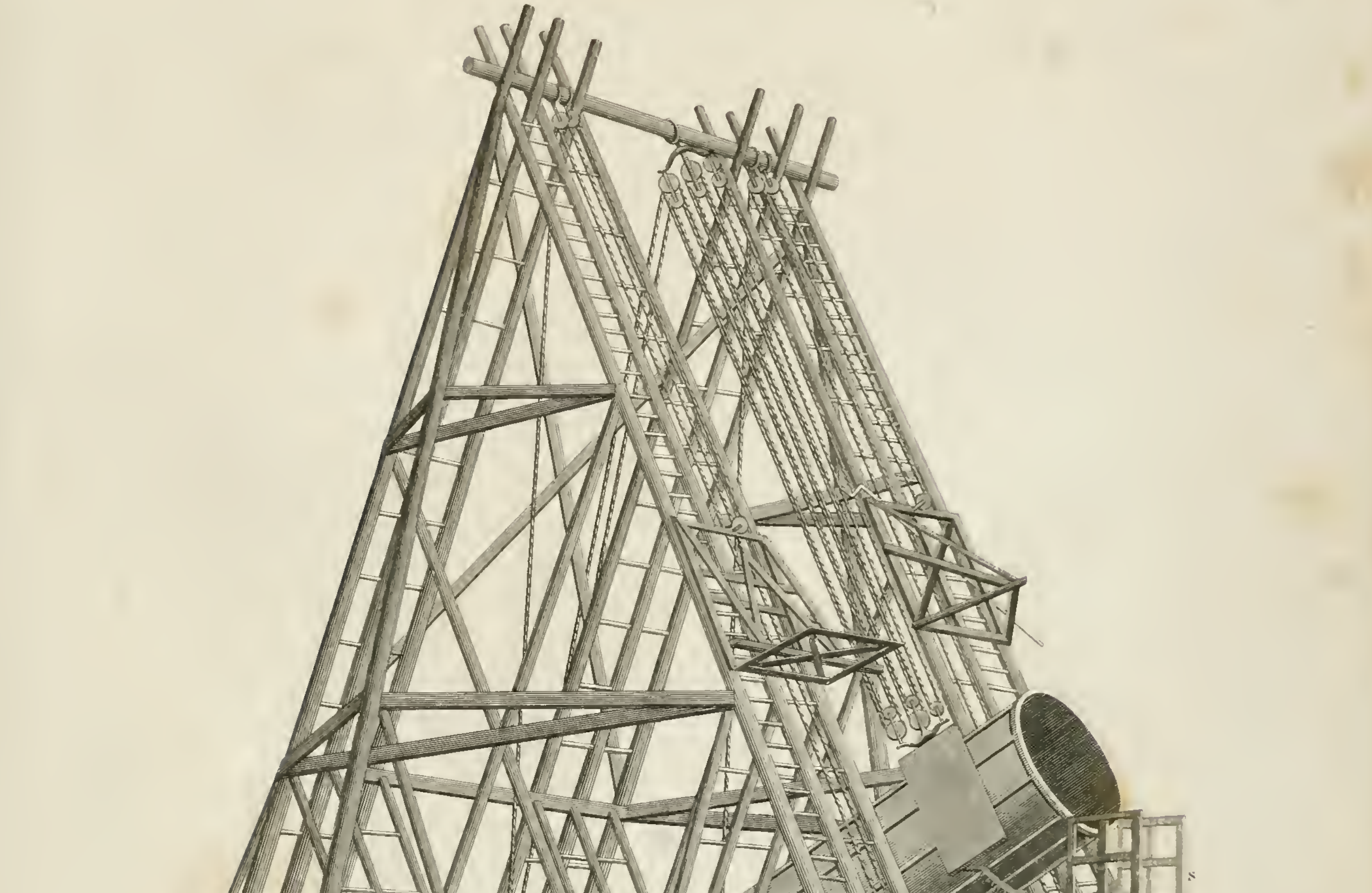


Eng^d by D. Haines

OPTICS. PLATE CCCCXLI.

SIR WILLIAM HERSCHEL'S GREAT FORTY FEET TELESCOPE.



OPTICS. PLATE CCCCXLII.

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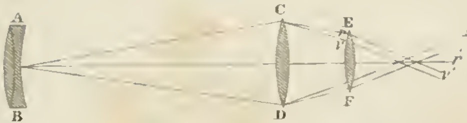


Fig. 2.

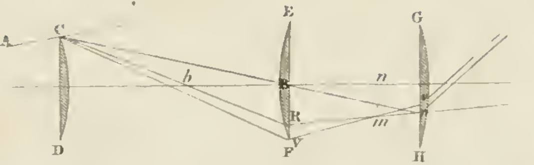


Fig. 9.

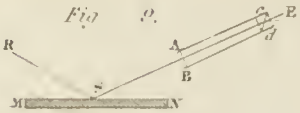
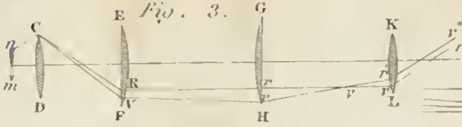


Fig. 3.



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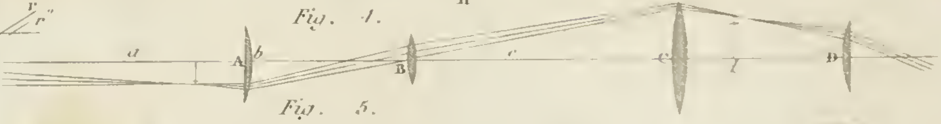

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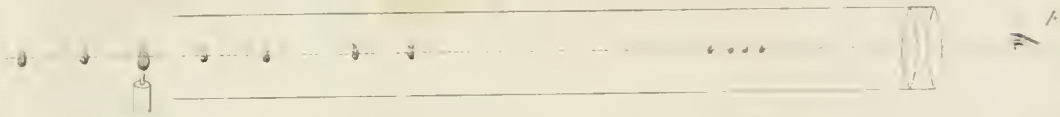

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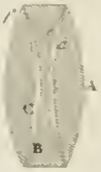

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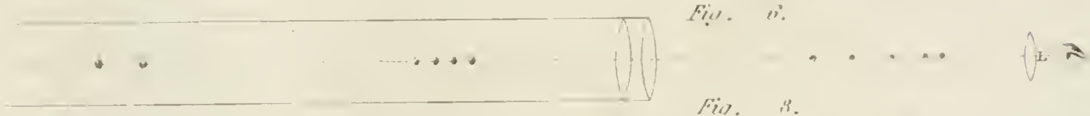

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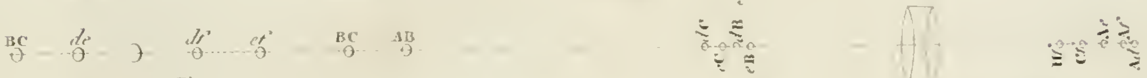

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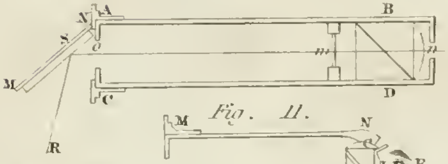

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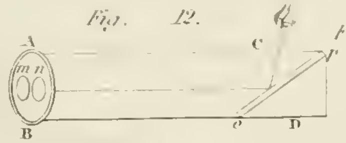


Fig. 15.

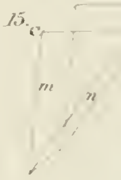


Fig. 15.

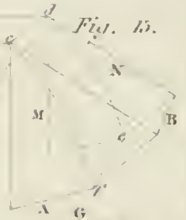
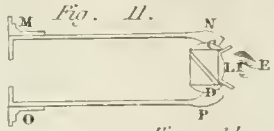


Fig. 11.



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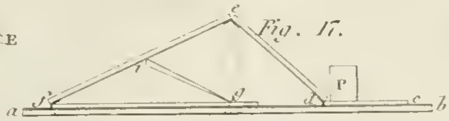
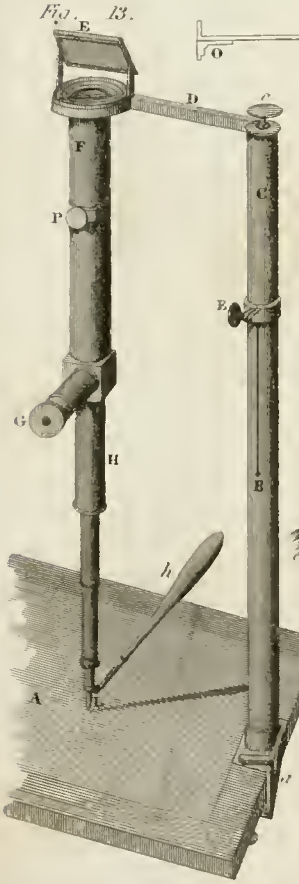


Fig. 13.



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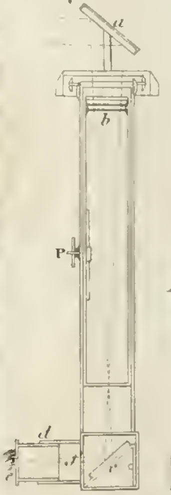

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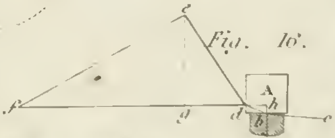

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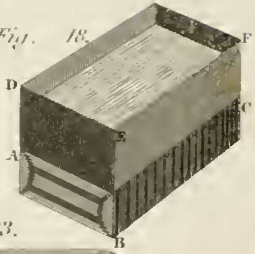

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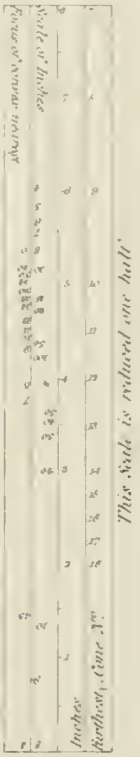


Fig. 19.

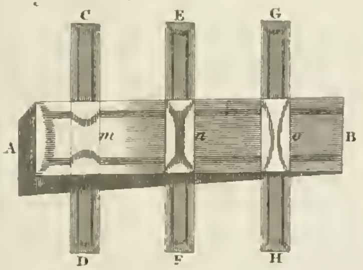


Fig. 23.

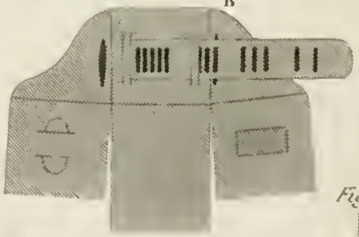
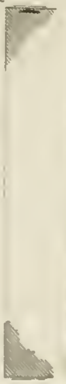
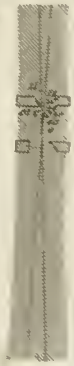


Fig. 25. *Fig. 26.*





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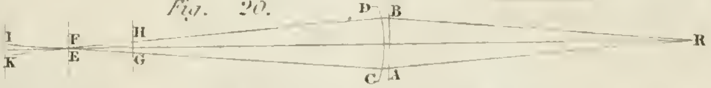
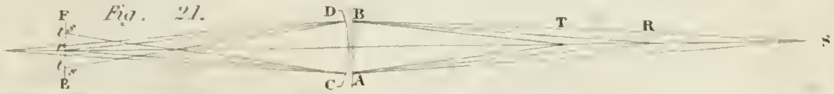


Fig. 21.



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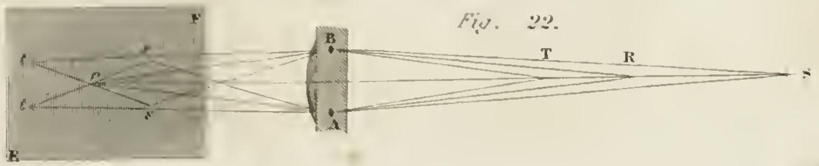


Engd by T. Haines

ORDNANCE.

PLATE CCCCXLIII.

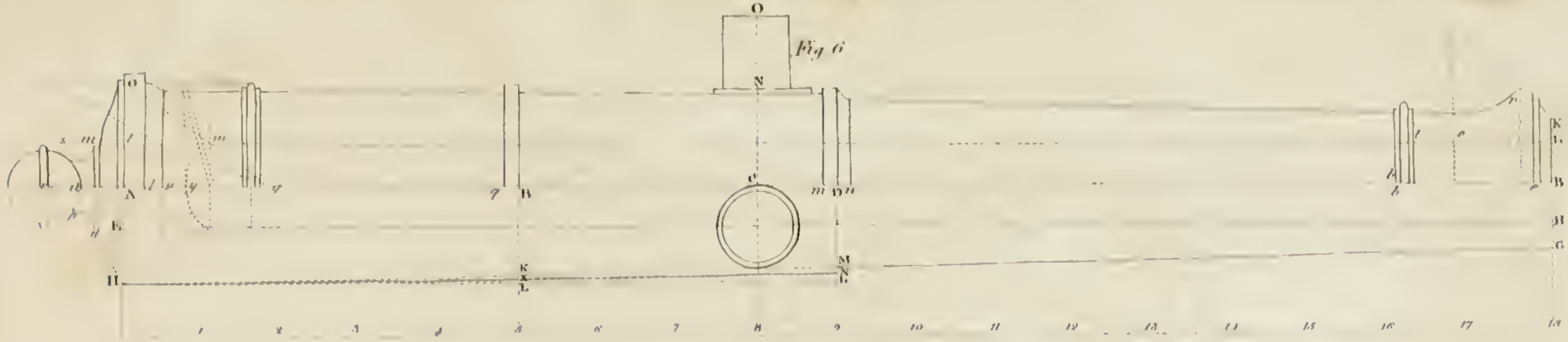


Fig. 6

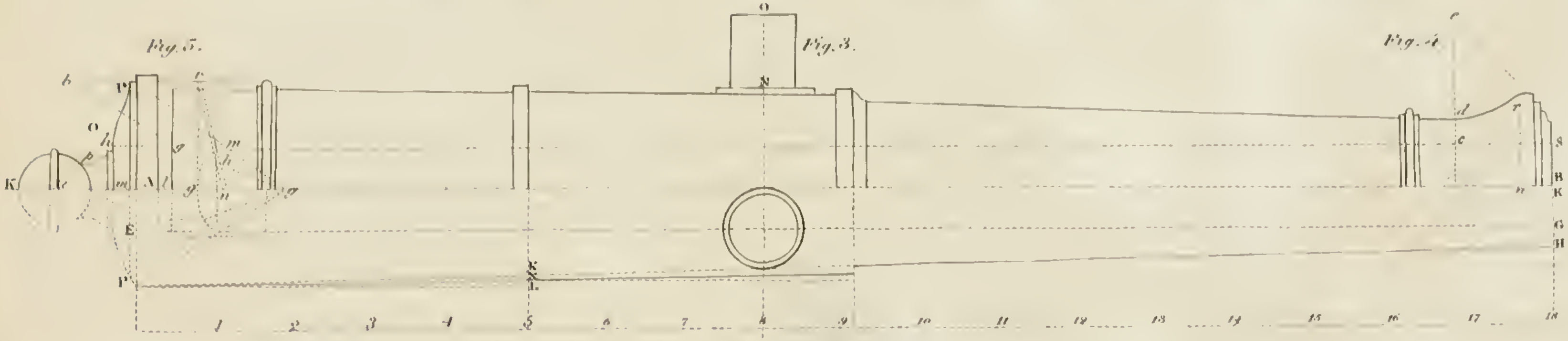


Fig. 5.

Fig. 3.

Fig. 4.

Fig. 2.

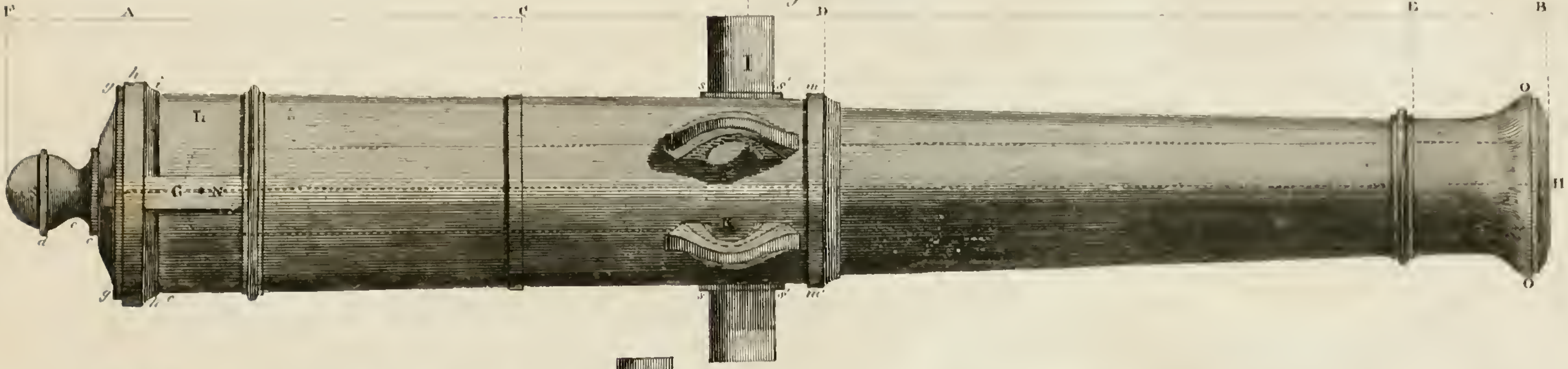
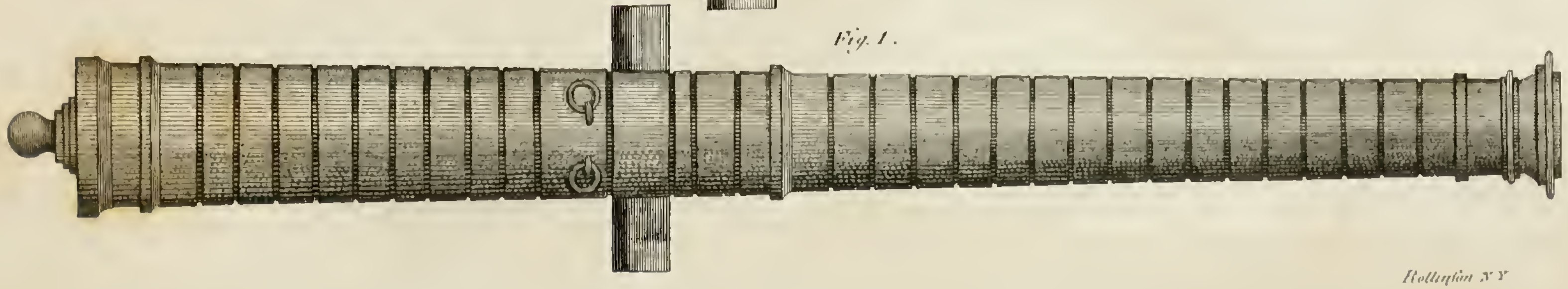


Fig. 1.

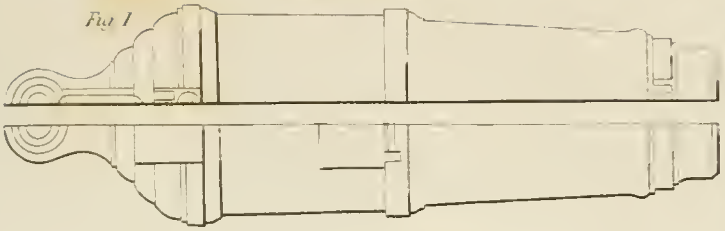


Rollinson N.Y

ORDNANCE. PLATE CCCCXLIV.

24 Pounder Carronade

Fig. 1



8 inch Brass Howitzer

Fig. 4.

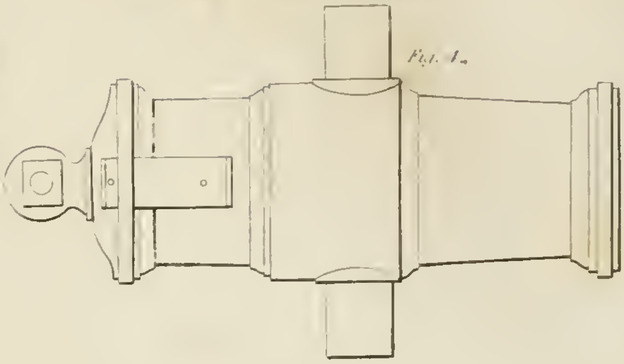


Fig. 2

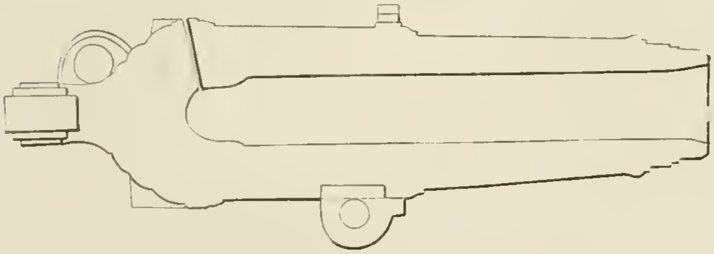


Fig. 5.

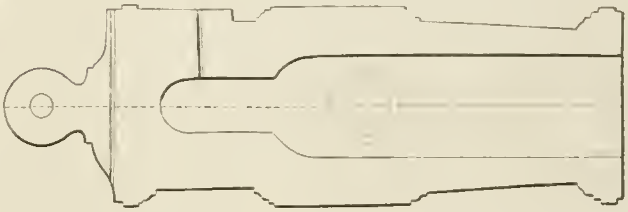
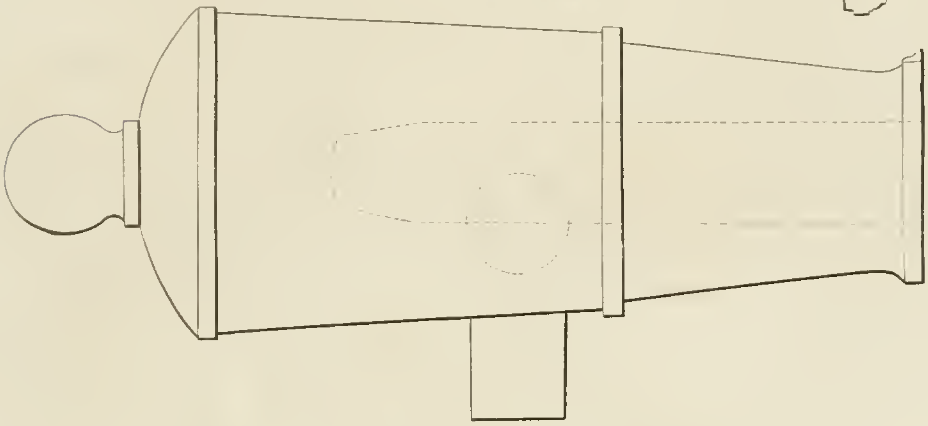


Fig. 3.
Iron 5½ inch Howitzer



10 inch Brass Mortar

Fig. 6.

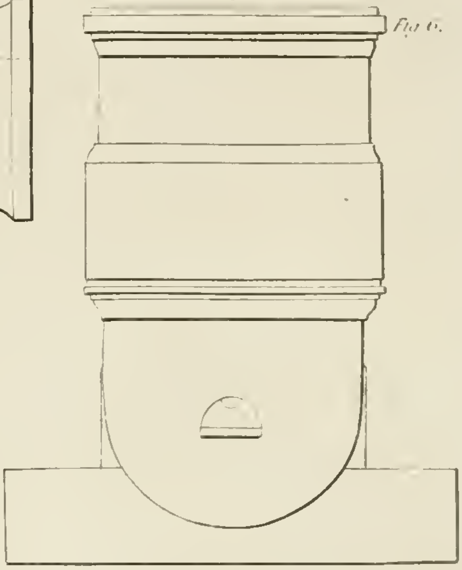


Fig. 10.
Howitzer

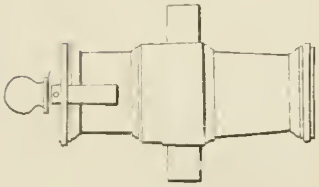


Fig. 8
13 inch iron Mortar

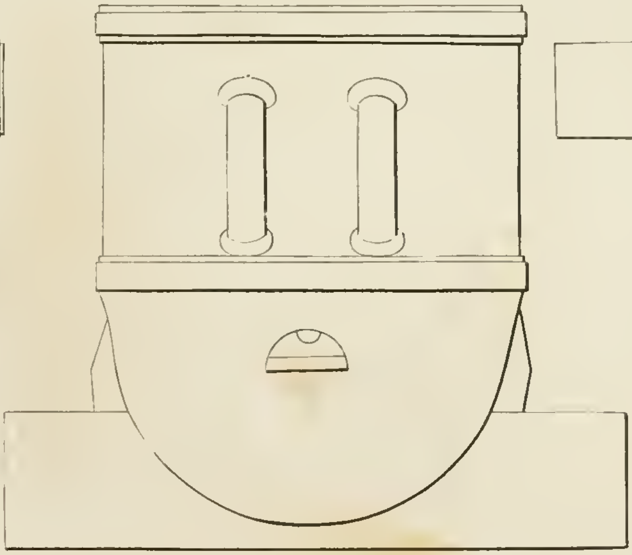
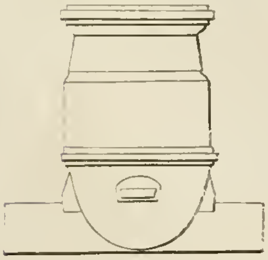
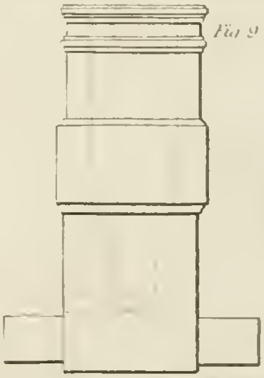


Fig. 7
5½ inch Brass Mortar

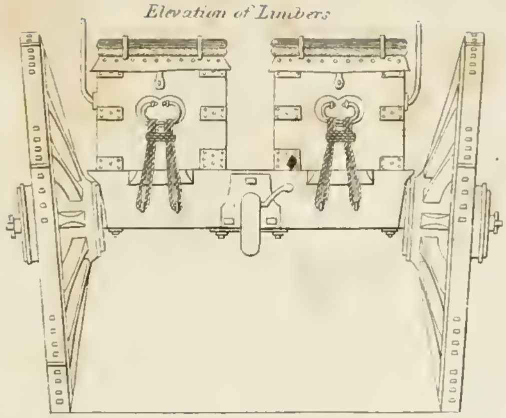


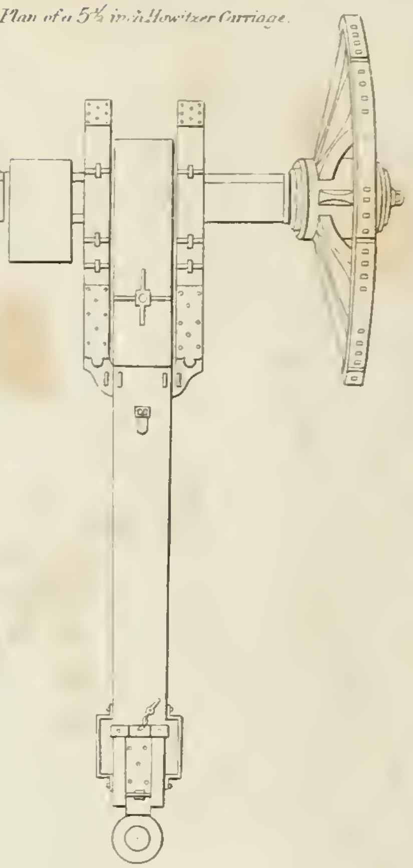
13 inch sea Mortar Reduced Scale

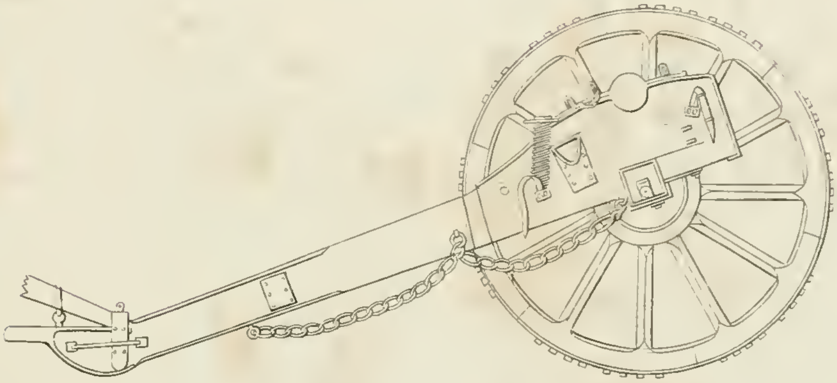
Fig. 9

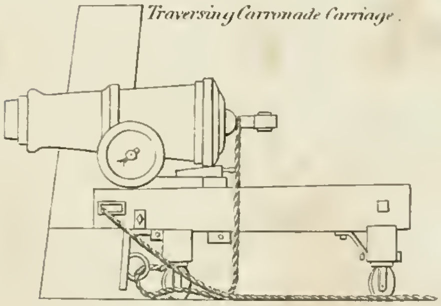


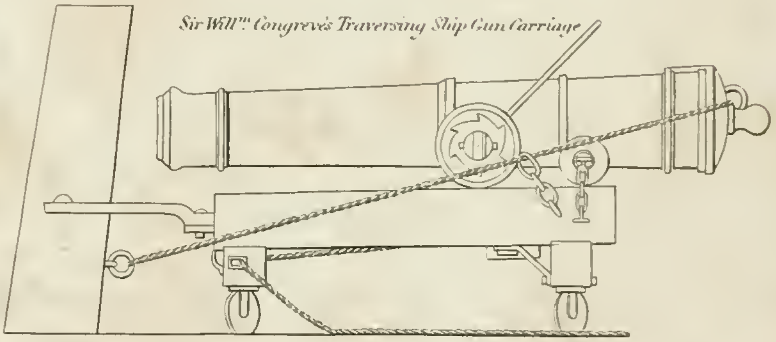
ORDNANCE. PLATE CCCCXLV.

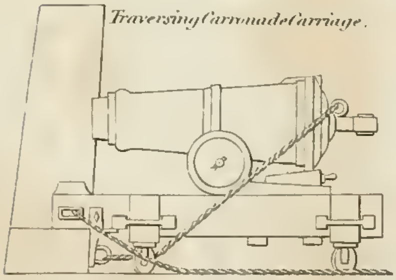

Elevation of Limbers

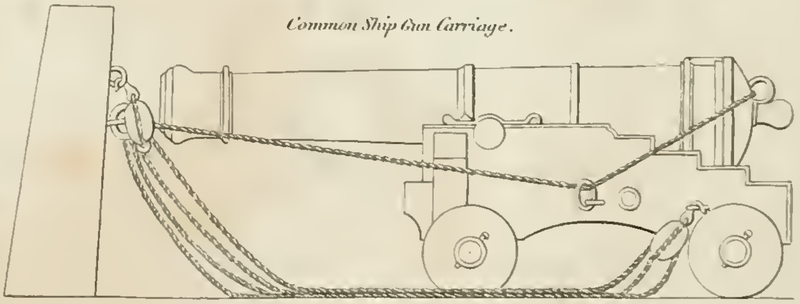

Plan of a 5½ inch Howitzer Carriage.


Elevation of Carriage.


Traversing Carronade Carriage.


Sir Will^m. Congreve's Traversing Ship Gun Carriage


Traversing Carronade Carriage.


Common Ship Gun Carriage.

Eng^d by R. Campbell

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PLATE CCCCXLVI.

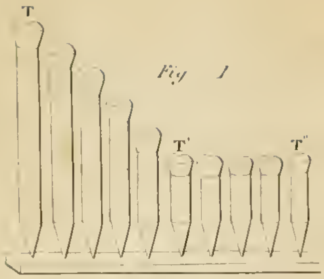


Fig. 1

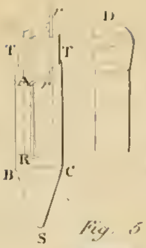
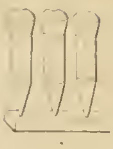
Fig. 2


Fig. 3


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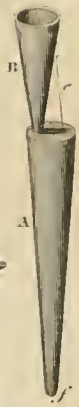

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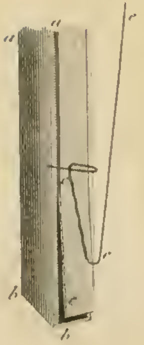

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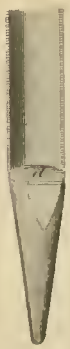

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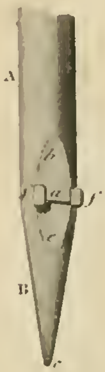

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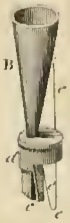

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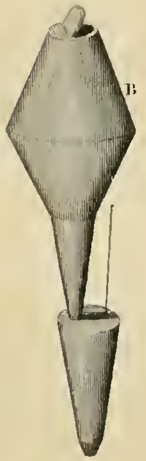

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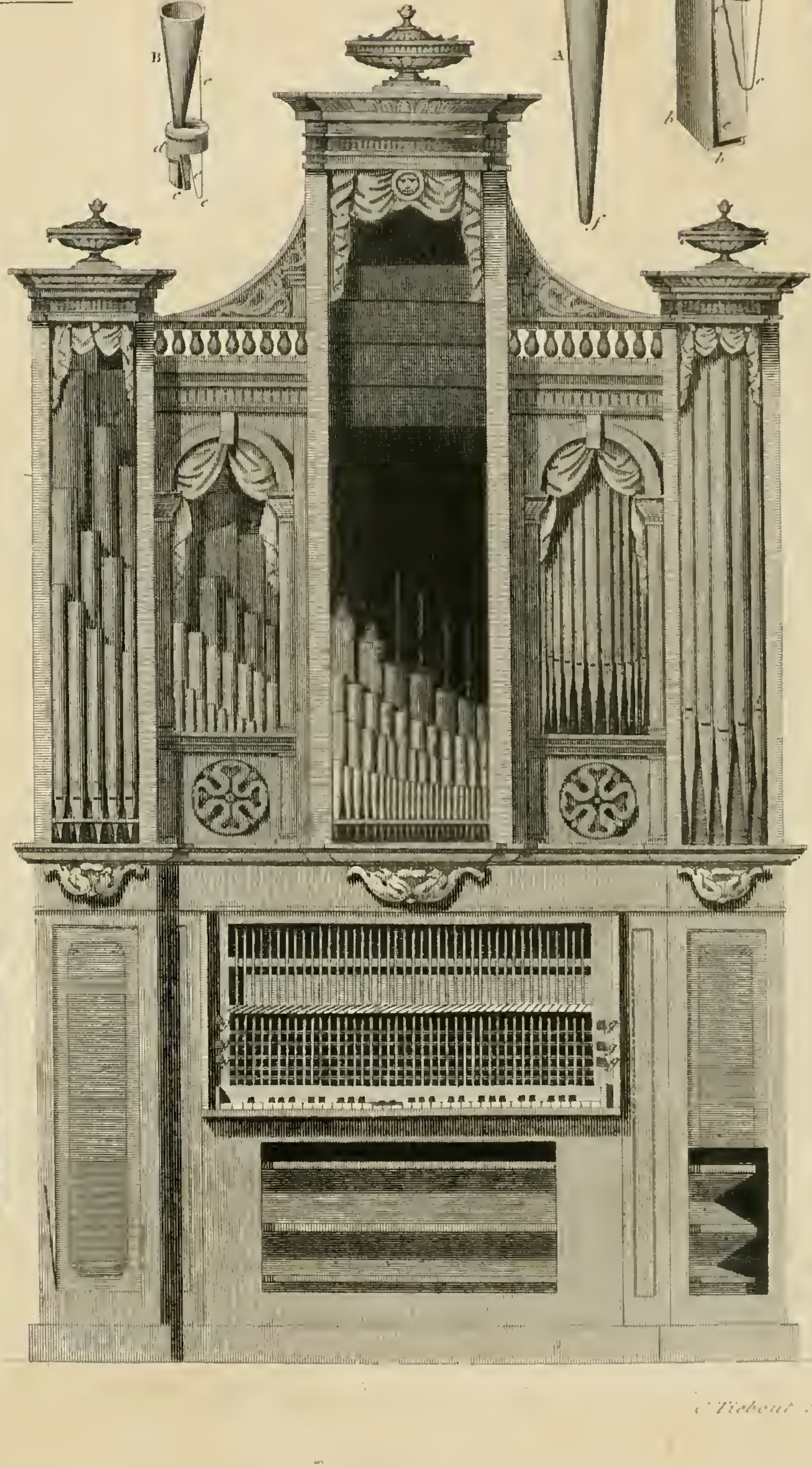

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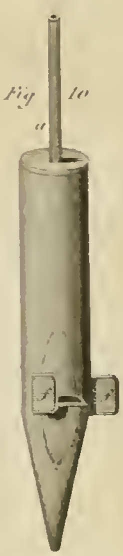

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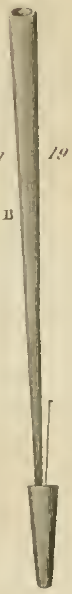

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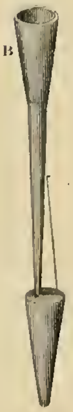

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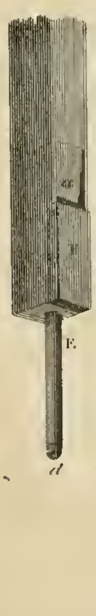

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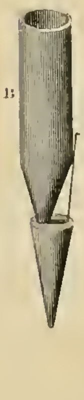

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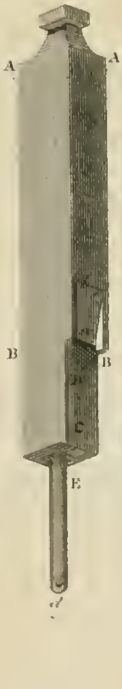

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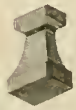

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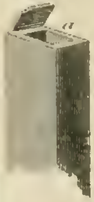

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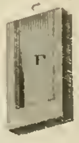

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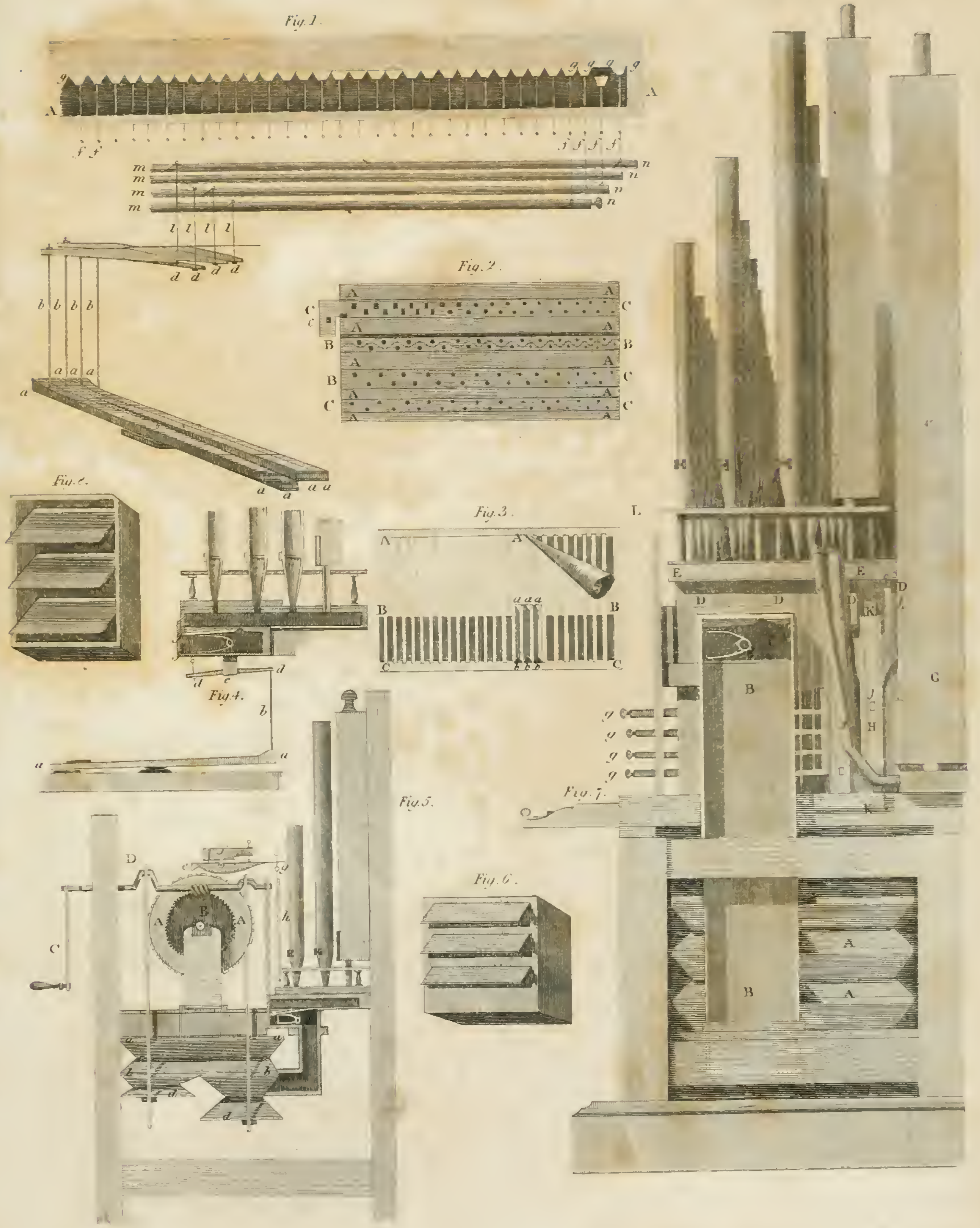
PLATE. CCCCXLVII.



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